Comparative Response of Self Consolidating Concrete Using Natural and Bloated lightweight Shale Aggregate Adding Mineral Admixtures

MS thesis

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MS Structure Engineering

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Declaration

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ABSTRACT

This paper presents the structural behavior of locally manufactured self-consolidating lightweight concrete (SCLWC) in comparison with self-consolidating normal weight concrete (SCNWC). In addition, cement is replaced by the Fly ash (FA) and Lime Stone Powder (LSP) in concrete. The bloated shale aggregate (BSA) was manufactured by expanding shale pellets of varying sizes by heating them up to a temperature of 1200℃ using natural gas as fuel in the rotary kiln. The main parameters studied in this investigation were the compressive strength, stress strain curve, modulus of elasticity and ultimate ductility of the concrete members made from the BSA and then were compared with self-consolidating normal weight concrete (SCNWC) using crushed stone as coarse aggregate. Four formulations have been made, one the control mix and the second having 20% replacement of cement with Fly ash and lime stone powder both having the same proportion by weight. The fresh properties and hardened properties of SCLWC and SCNWC were studied. The Slump flow, V-funnel, J-Ring and L-box tests of SCLWC were conducted and it gives the suitable result when compared with SCNWC. There is no significant (2-4%) reduction in the compressive strength of SCLWC while 16.1% reduction in flexural strength is noted. Light weight aggregates tend to shift concrete behavior from ductile to brittle causing reduction in flexural strength. Addition of LWA reduced the density of SCLWC up to 35%. This reduction in density can reduce the verall cost of the structure because of dead load reduction.

Dedication

I dedicate this Research to

Dr. Muhammad Usman, Dr. Syed Ali Rizwan my mentors

And

To my parents

Acknowledgments

I am thankful to Allah Almighty, The Most Gracious and The Most Bountiful, who gave me the strength to complete this dissertation. After that, I would like to express sincere gratitude to my mentor and advisor Dr. Muhammad Usman for his continuous support for his continuous support, guidance and valuable discussions on the topic throughout the research phase. His doors were always remains open for me and he guided me towards the right path whenever I stuck at any phase of the research.

I am thankful to Prof. Dr. Syed Ali Rizwan for his co-operation, guidance and valuable advice. I am also indebted to all the faculty members of NUST Institute of Civil Engineering (NICE) for their knowledgeable suggestions.

My profound thanks are due to my class fellows and Structures lab staff for their help and co-operation in the experimental lab work. Thanks are also due to my senior who always responded positively whenever I called her for the help.

Last but not the least; I would also like to thank my parents as this research work would not have been completed without their constant support and prayers.

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CHAPTER 1

1 INTRODUCTION

1.1 Background

Nowadays, the concrete mix design mainly focused on the durability of concrete besides its compressive strength [1]. Lately, In the field of materials a lot of research has been done to develop concrete with special properties for structural applications [2] . From the environmental aspect, the creation and utilization of cement concrete and other building materials are of huge significance [3]. The SCC is that type of concrete which deform effectively and high resistance to segregation as per ACI committee 237R-07 [4]. The SCC flows to fill up the accessible space under its own weight and needs no compaction [5]. Self-consolidating lightweight concrete (SCLWC) is an innovative concrete that chains the advantages of both lightweight concrete (LWC) and self-consolidating concrete (SCC). Therefore, for successful project the use of lightweight concrete will provide an economical solution for the various engineering applications. In SCC production, there is not a much-perceived plan process and the production is conceivable with different ingredients. Each component of SCC and its properties may have a different influence on the self-compacting characteristic. Henceforth, a mixture prepared as per any given method for SCC may not really show self-compacting properties. Trial mixes are important for the necessary final conclusion [6].

Over the most recent couple of decades, the lightweight concrete increase considerably more preference from the researchers in spite of the fact that it utilizes could follow back to 3000 BC [7]. Lightweight concrete (LWC) is favorable over concrete having normal weight in view of dead load reduction, simplicity of taking care of, and good strength [8]. As per ACI 213R, The air-dry unit weight of structural lightweight concrete ranging from 1350 to 1900 kg/m^3 and the minimum compressive strength of 17 MPa [9]. TS2511 characterizes the basic lightweight concrete as a concrete having a unit weight under 1900 kg/m^3 and 28-day compressive strength of more than 16 MPa. As per TS EN 206-1, the oven dry density of lightweight concrete lie between 800- 2000 kg/m^3, all or part of the total lightweight aggregate is utilized to produce lightweight concrete of this density. The statement given by ACI 213R and TS 2511 are the meanings of 'structural lightweight concrete', while the statement of TS E206-1 characterizes the 'lightweight concrete' as a general type of concrete [6]. In the previous decades, LWC has been produced utilizing different sorts of lightweight aggregates (LWA’s) such as expanded perlite [10-15] hollow glass beads [13, 14, 16-18], expanded clay [14, 19] and expanded polystyrene beads [18, 20-24].

SCC and LWC are two commonly utilized materials in development industry attributable to their specific qualities and points of interest. The mixture of SCC and LWC gives the advantages of both. Considering the decreased structural weight and easy to place, self-compacting lightweight concrete (SCLWC) might the response to the expanding development necessity for slenderer and the element which are highly reinforced. Achievement in modern concrete technology presents the SCLWC as workable and mass reducing material. In any case, there are limited investigations to demonstrate its appropriateness in widely range application in this real world [25, 26]. For limiting the flow segregation in self-consolidating concrete high cement content i.e. 500-600 kg/m^3 has required. Similarly in lightweight concrete (LWC) high cement content is required, however there is very less investigation in self-consolidating lightweight concrete properties [5]. Hwang and Hung works on self-consolidating lightweight concrete durability aspect and concluded that SCLWC could achieve workable flowability, better strength and high durability performance [5, 27].

The fresh concrete behavior from mixing up to compaction depends essentially on the workability of concrete. SCLWC is more delicate to the difference in materials type and proportion; along these lines, the alteration of the mixture proportions requires achieving the satisfactory flowability which may affect the hardened concrete performance. In this manner, it is necessary for concrete to have satisfactory fresh properties that will affect the response of hardened concrete including strength and durability [25, 26]. The mixture design of SCLWC does not follow precisely the mix design of LWC or SCC; be that as it may, the inspection in both LWC and SCC still governs the SCLWC mix design [26]. Existing created strategies for mixture design of SCC in the literature may concentrate on the fresh properties and mixture proportion to accomplish the required flowing ability and self-compacting ability, instead of the compressive quality. Consequently, the strength prerequisite in SCLWC needs more thought [29, 30].

1.2 Problem Statement

The Normal weight concrete use significantly increases the demand of normal weight aggregate (NWA). Due to this there is significant reduction in natural stone deposits and a lot of damage to natural ecosystem. Also Due to increase in the self-weight of structure, natural weight aggregate is not favorable for long span bridges, tall buildings, and floating structures.

The use of typical high strength lightweight concrete that vary between 34 and 69 MPa is one of the mean of overcoming such limitations. The air-dry density of these concrete does not exceeds 2000 kg/m^3.in Accordance to ASTM C567.The lightweight concrete in construction sector has been helpful such as reduce the seismic risk and a lot of damage risk has been controlled. The use of structure lightweight concrete in the construction sector is beneficial such as decreasing the earthquake load on the structure as well as the risk of the damage.
Design procedure and statistical model for normal weight SCC has been developed in the previous research. However lack of research studies in the field of SCLWC (self-consolidating lightweight concrete) warrants investigations.

1.3 Research Objectives

- This study goals to relate the engineering properties of SCNWC with those SCLWC. For this purpose, a conventional coarse aggregate was fully substituted with coarse lightweight shale aggregate. The effect of fresh and hardened properties were also examined.
- This study is carried out to develop a lightweight shale aggregate self-compacting concrete from locally manufactured material (expanded shale). To access the Flyash and limestone powder (LSP) effect on the fresh parameters, compressive strength, homogeneity, porosity, the microstructure of concrete and density of self-consolidating lightweight concrete (SCLWC).
- Evaluation and comparison of effect of different components in response of SCLWC (Shale as lightweight coarse aggregate) mix design and normal conventional aggregate concrete in term of their compressive strength and stress strain behavior (Flexural behavior).

1.4 Research Significance

Nowadays, lightweight shale aggregate have the lightest density among the mortar matrix and natural stone aggregate in concrete. Due to vibration, SCC has been useful for preventing the moment of lightweight aggregate in concrete. A number of significance of SCLWC has been mentioned follow.

- It is governed primarily by economic considerations.
- Eliminating the need of vibration and reduce the noise pollution.
- Decreasing the permeability and improving durability of concrete.
- Reduce seismic forces and improved structural efficiency.
- Structural dead load will reduce.
- Smaller section as well as smaller sized foundation can be used.
- Low pressure on the formwork.
- Improved the ease of transport and constructability.

1.5 Research Methodology

The methodology adopted to study the effect of normal and bloated lightweight aggregate on the self-consolidating concrete system is given below:

1. Literature review has been carried out on the subject topic.
2. For characterization and composition of Lightweight aggregate (LWC), X-ray Diffraction (XRD), X-ray Fluorescence (XRF) and Scanning Electron Microscopy (SEM) techniques were utilized.
3. Self-consolidating normal weight concrete and Self consolidating lightweight concrete (SCLWC) formulations were prepared by addition of varying percentage of mineral admixtures (Fly ash and Limestone Powder).
4. Laboratory tests were performed. These include tests for Slump flow test, J-ring test, V-funnel Test, L-box test, density, air contents, absorption capacity and hardened properties were measured.
5. To have insight into the effect of LWA in SCC based formulations, Scanning Electron Microscopy test was conducted at the age of 28 days.
6. Finally the discussions were made on the topic with the help of relevant literature and supervisor’s guidance.

1.6 Research Scope

Concrete has undergone rapid and phenomenal development in the past few years and is of utmost importance to the construction industry. As a result, lightweight concrete is emerged as the concrete which serves both economic and environmental purpose. Lightweight self-consolidating concrete(LWSCC) is a new type of concrete that combines the advantages of both lightweight concrete(LWC) and self-consolidating concrete(SCC) Therefore, for successful project the use of lightweight concrete will provide an economical solution for the various engineering applications. That’s why to reduce the seismic risk, it is important to reduce the mass of the structural building. This can be done by the use of structural lightweight concrete in construction [31].

CHAPTER 2

2 LITERATURE REVIEW

2.1 Introduction

Although the use of lightweight concrete has been recorded back in 3000 B.C[7], the more significant work on lightweight concretes has been carried out in last few decades[12, 26, 32-35]. The usage of the lightweight concrete decreases overall weight of concrete resulting in reduced structural elements dimensions [36, 37]. This can result in the cost-effectiveness of structures such as long-span bridges and high rise buildings. In addition to the lower weight, lightweight concrete shows better thermal resistance than ordinary concrete [37-39]. Furthermore, due to its lightweight porous structure, LWC exhibits excellent thermal conductivity [1, 33, 40], ease of placement [41] and better strength[8].

2.2 Self-Compacting Cementitious Systems

Self-compacting cementitious system (SCCS) are composed of three phases/systems, It is important to understand all these systems, paste has to be optimized first which is the basic component of all three systems, followed by the mortar system and finally leading to SCC systems.

- Self-Compacting Paste (SCP) System (Single component)
- Self-Compacting Mortars (SCM) System (Two component)
- Self-Compacting Concrete (SCC) System (Three component)

Numerous studies on the self-compacting cementitious systems (SCCS) have been made all across the world including Pakistan, as the technology is still in stages of development [42]. Few significant and imperative studies can be summarized as follows

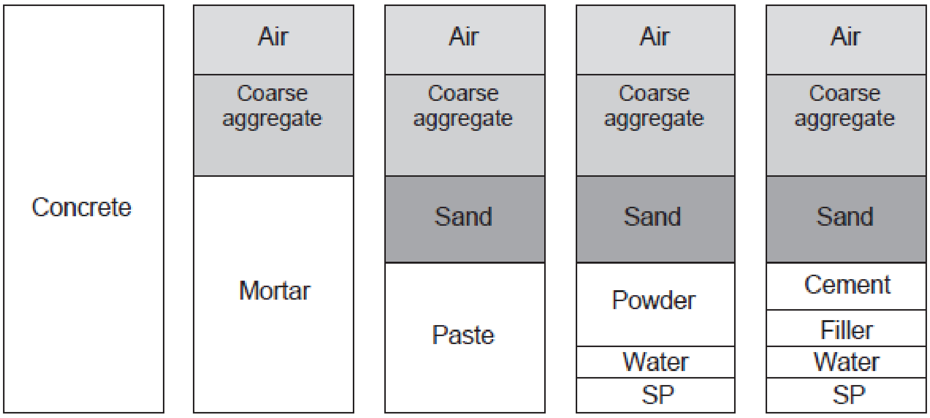


Figure 2-1: Schematic composition of SCCS [43]

Rizwan et al reports that "as paste is the vehicle of aggregate phase, good workability can be achieved by reducing the aggregate content with an increased paste volume thus resulting in reduced internal friction."[43]. Further it is suggested that the sand content smay be increased to augment the cohesiveness and stability of the concrete mix. This may also result in higher requirement of super plasticizer (SP) content to achieve the selected target flow and a slightly lower modulus of composite. Regarding the aggregate requirement, the study specifies that no more than 15% of aggregate should be elongated as these can cause internal friction, bigger voids and bleeding and require a higher paste volume. Then for the mixing water, the study describes the effect of mixing water temperature, on the flow response of self-compacting cementitious systems and suggests that any addition of even small quantity of water after the chemical admixtures have been added could significantly reduce the mix cohesion and or could yield slightly inaccurate results which appears contradictory to the literature [44].

Hence, self-compacting concrete is characterized with low w/p ratio, use of super plasticizer, higher powder content to produce adequate paste to act as lubricant for the aggregate phase, use of viscosity modifying agents and use of smaller size as well as lesser content of aggregate possibly with continuous grading [46].Apart from all the advantages offered by SCCS, it has certain limitation as well. A careful selection of materials and admixture is very critical to the functioning of SCC. The initial material cost is slightly high as compared to conventional concrete because of the use of various chemical or mineral admixture and fine materials [46]. The cost effect is subdued by requirement of less labours on site and use of mineral admixtures.

2.3 Definition of Lightweight concrete (LWC)

Lightweight concrete for structural applications refers to concrete with density less than 1840 kg/m^3 and minimum compressive strength of 17.2 MPa made with lightweight aggregate whose unit weight should not exceed 1120 kg/m^3, as per ACI Committee 318 requirements (ACI 318 2008).

The use of lightweight aggregates can be traced back to thousands of years. Lightweight aggregates used in pre-historic times were of natural origin. Scoria, pumice, tuff etc. and sometimes were volcanic. LWA were used in famous towns of Mohenjo-Daro, Harappa in Indus valley civilization. Aqueducts, pantheon and Colosseum in Rome were all built using lightweight aggregates. Natural lightweight aggregate scoria and pumice are shown in **Figure 2.2.**

The demand of lightweight aggregates is ever increasing. Depletion of natural resources for LWAs worldwide has led to development of new techniques for the production of LWAs. Raw materials like shale, clay and slate etc and By-products of industry like blast furnace slag, and ashes like fly ash and bed ash are being used to produce LWAs.

Lightweight aggregates have lower densities compared to normal weight aggregates that range above 1500 kg/m^3. The densities of LWAs vary in a wide range from 50 kg/m^3 to 1000 kg/m^3. These aggregates are being used to develop different types of concrete from high strength to high fire endurance concretes.

Lightweight aggregates are expensive, but this issue is subsidized by other governing factors like it is easy for the workers to handle, also demolition of a structure made from LWC will be easy and lesser energy will be consumed. Alongside these benefits LWC provide thermal insulation and are inherently fire resistant. In the present research expanded shale lightweight aggregate has been used for the production of lightweight concrete.

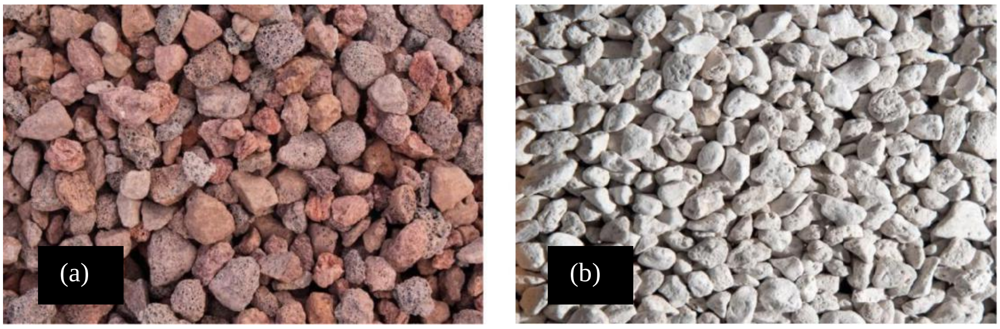


Figure 2-2: (a) Scoria aggregate (b) Pumice aggregate

2.4 Production of lightweight aggregates

Lightweight aggregates that exist naturally like scoria, pumice can be crushed, sieved and can be used for production of LWC. These materials are lightweight and strong enough to be used in production of LWC. These aggregates are of low density, small interconnected voids can be seen in case of scoria. While in pumice the shells are not well connected.

Natural material materials and industrial by-products need processing like bloating, expansion, agglomeration and fusion before they can be used for production of lightweight concretes. All the processes require heat treatment, the heat treatment can be provided using bed reactors, kilns and industrial furnaces. Industrial kilns like rotary and vertical shaft kilns can be used to expand the natural raw material. The process is simple, raw materials are fed at the top of kilns while heat is provided at the lower end. The materials are moved to heating chamber where temperature increases and expansion takes place. The heat treated material is then fed to a cooler, where cool wind lowers the temperature of expanded LWAs. A typical rotary kiln is shown in **Figure 2.3** [18]. Expanded shale, clay and slate can be produced using the kiln heat treatment method. Sintered strand, foaming bed reactor and cold bonding processes are used for production of LWAs where industrial by-products are being utilized. The method of production of "expanded shale aggregate" used in present study is discussed in following section.

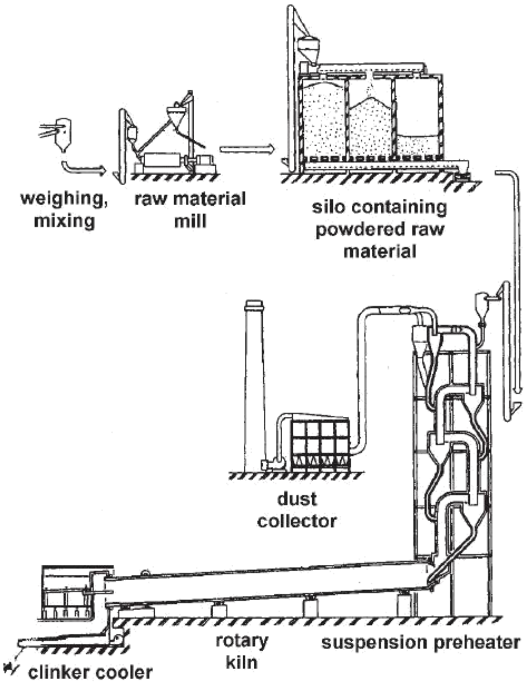


Figure 2-3: Rotary kiln for production of expanded LWAs [18]

2.5 Production of expanded shale LWA

Rotary kiln method is employed for the preparation of expanded shale lightweight aggregate. Raw material (Shale) is fed into storage silos. These silos slowly feed the natural rocks to preheaters, which heat the material to moderate temperature. The preheated material is then injected in the upper end of rotary kiln where it slowly revolves down to firing chamber. Heat treatment at 1200℃ makes the shale sufficiently plastic, here is when the expanded gases form small interconnected cells. A scanning electron microscopy image showing the pores and interconnected cells is shown in **Figure 2.4**.

The expanded material (clinker) is then fed to a cooling chamber. After cooling, the expanded shale lightweight aggregates are crushed and screened. Then expanded LWAs are tested for physical properties like moisture content, specific gravity, water absorption and unit weight etc.

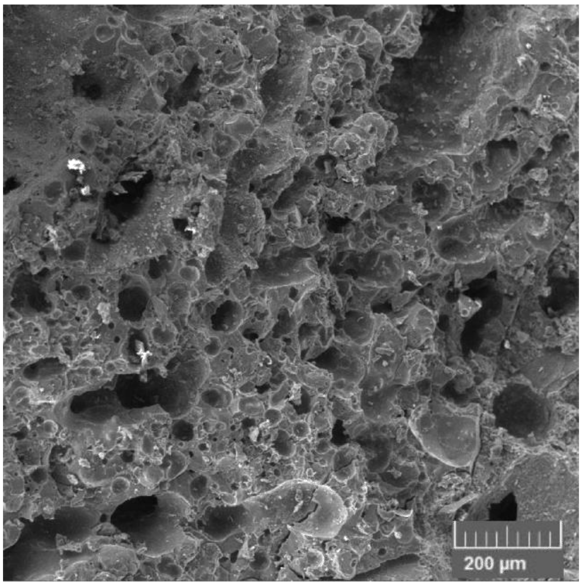


Figure 2-4: SEM micrograph of expanded shale LWA (present work)

There are mainly two types of lightweight aggregate (LWA). The first comprises of artificially produced lightweight aggregate such as expanded clay, expanded shale, expanded slate, expanded perlite, exfoliated vermiculite, sintered pulverized-fuel ash, foamed blast furnace slag, expanded glass and so forth. The second category of lightweight aggregate (LWA) is natural materials and other types that include pumice, scoria, diatomite as well as wood particles and plastics.

2.6 Development of LWC and its Applications

Even though the history of the use of lightweight aggregate (LWA) stem from the early days of the Roman Empire, the earliest structural use of lightweight concrete in the USA was in the construction of concrete ship in 1912. In 1922, the first highway bridge was constructed using concrete with expanded shale aggregate[47]. Since then concrete and composite bridges containing LWAs had been built in United States and Canada because of the benefits. Such as 25 to 35% of reduction in the dead load and over 10 to 20% of cost savings. Lightweight may cost more per unit volume than the normal weight concrete due to higher relative cost of producing lightweight aggregate and its preparation needed prior to their use in the concrete.

2.7 LWC AND SCC

Nowadays, the concrete mix design mainly focused on the durability of concrete besides its compressive strength [1]. Lately, a lot of research has been done in the field of materials to develop concrete with special properties for structural applications [2] . Relentlessly expanding measures of industrial wastes because of fast urbanization and industrialization is a basic issue. Overseeing such wastes adequately and effectively is a regularly developing research field [39]. From the environmental aspect, the creation and utilization of cement concrete and other building materials are of huge significance [3]. The SCC is that type of concrete which deform effectively and high resistance to segregation as per ACI committee 237R-07 [4]. The SCC flows to fill up the accessible space under its own weight and needs no compaction [5].

Concrete has undergone rapid and phenomenal development in the past few years and is of utmost importance to the construction industry. As a result, lightweight concrete is emerged as the concrete which serves both economic and environmental purpose. Self-consolidating lightweight concrete (SCLWC) is an innovative type of concrete that chains the advantages of both lightweight concrete (LWC) and self-consolidating concrete (SCC). Therefore, for successful project the use of lightweight concrete will provide an economical solution for the various engineering applications

Over the most recent couple of decades, the lightweight concrete increase considerably more preference from the researchers in spite of the fact that it utilizes could follow back to 3000 BC [7]. Lightweight concrete (LWC) is favorable over normal weight concrete in view of the reduction in dead loads, simplicity of taking care of, and better strength [8] . SCC and LWC are two commonly utilized materials in development industry attributable to their specific qualities and points of interest. The mixture of SCC and LWC gives the advantages of both.

Considering the decreased structural weight and easy to place, self-compacting lightweight concrete (SCLWC) might the response to the expanding development necessity for slenderer and the element which are highly reinforced. Achievement in modern concrete technology presents the SCLWC as workable and mass reducing material. In any case, there are limited investigations to demonstrate its appropriateness in widely range application in this real world [25, 26]. For limiting the flow segregation in self-consolidating concrete high cement content i.e. 500-600 kg/m^3 has required. Similarly in lightweight concrete (LWC) high cement content is required, however there is very less investigation in self-consolidating lightweight concrete properties [5]. In the previous decades, LWC has been produced utilizing different sorts of lightweight aggregates (LWA's) such as expanded perlite [10-15] hollow glass beads [13, 14, 16-18], expanded clay [14, 19] and expanded polystyrene beads [18, 20-24]. Hwang and Hung works on self-consolidating lightweight concrete durability aspect and concluded that SCLWC could achieve workable flowability, better strength and high durability performance [5, 27].

Shami and Behnam [49] studied mix design of lightweight self compacting concrete (LWSCC). In which they investigated the previous work on LWSCC regarding its mix proportion, density and mechanical properties and they analyzed that data. The analyzed results were showed in statistical expression. The results showed that in future research it will be helpful to choose a proper component with different ratios and curing conditions.

As per ACI 213R, "Structural lightweight concrete has an air-dry unit weight ranging in the vicinity of 1350 and 1900 kg/m^3 and the minimum compressive strength of 17 MPa" [9]. As per TS EN 206-1, the oven dry density of lightweight concrete lie between 800- 2000 kg/m^3, all or part of the total lightweight aggregate is utilized to produce lightweight concrete of this density. The fresh concrete behavior from mixing up to compaction depends essentially on the workability of concrete. SCLWC is more delicate to the difference in materials type and proportion; along these lines, the alteration of the mixture proportions requires achieving the satisfactory flowability which may affect the hardened concrete performance. In this manner, it is necessary for concrete to have satisfactory fresh properties that will affect the response of hardened concrete including strength and durability [25, 26]. The mixture design of SCLWC does not follow precisely the mix design of LWC or SCC; be that as it may, the inspection in both LWC and SCC still governs the SCLWC mix design [26]. Existing created strategies for mixture design of SCC in the literature may concentrate on the fresh properties and mixture proportion to accomplish the required flowing ability and self-compacting ability, instead of the compressive quality. Consequently, the strength prerequisite in SCLWC needs more thought [29, 30].

Due to the porous structure of lightweight aggregate, the adsorption capacity is very high with reasonable compressive strength. So to achieve the desirable workability and better strength, lightweight aggregate require more water. However the lightweight porous structure, the density is very less and having an excellent thermal conductivity [1]. The Self consolidating lightweight aggregate (SCLC) is highly flowable concrete which remove air without the supply of compacting energy and which has the characteristic of high resistance to sedimentation and to the segregation regarding the lightness of the lightweight aggregate respectively. It is however possible to achieve the desirable flowability of the concrete by adding super plasticizer or by increasing the paste content , but this also cause the concrete to segregate.

In Earthquake, the seismic forces, which have great influence on the mass of structure and buildings.Therefore to minimize the seismic risk, one should reduce the mass of the structure.This problem can be solved by the use of lightweight concrete in building constructions [31].

The use of chemical admixture like fly ash and limestone powder, either of this may not give the suitable response in fresh and hardened states in self consolidating concrete. If the limestone powder is used separately in SCC, it will increase the SP demand of the system and high early shrinkage will occur. On the other side if fly ash is independendly used in SCC, it may increase retardation period; although it improve the workability and upto certain extent reduce the shrinkage.

The change in the response of Self compacting system occur significantly due to secondary raw materials (SRMs) because of its prosity, particle size, shape and morphology [53]. The use of mix blend of fly ash and limestone powder will significantly improve the response of the system.

CHAPTER 3

3 Experimental Program

3.1 Materials

The Ordinary Portland Cement (OPC) Type –I conforming to ASTM C-150/C-150M-15 was selected as binder for both normal self-consolidating concrete (NWSCC) and lightweight self-consolidating concrete (LWSCC) specimen. Chemical properties of OPC analyzed through XRF and some of its physical characteristics obtained through various laboratory tests are presented in the table below.

Table 3-1: Chemical composition of different materials

Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	Cl
Fly Ash	55.32	0.26	6.54	6.78	1.22	2.39	0.19	1.14	---
LSP	8.64	0.84	0.82	46.76	1.65	0.10	0.02	0.11	---
OPC	20.51	5.25	3.39	61.53	2.33	0.77	0.31	2.84	0.01
Shale	42.55	14.55	8.60	13.59	2.32	1.83	0.31	0.05	0.04

Class F Fly ash was obtained and kept in sealed container to prevent from the moisture. Lime stone powder was obtained from Margalla crush. It was washed, oven dried and ground to powder to be used in cement mixes. It was also kept in the container similar to FA. It was made sure that both SRMs were free from lumps before using it for the mix. The fine aggregate used in the research is natural sand acquired from lawrencpur region having fine modulus of 2.25 and used in saturated surface dry condition (SSD). It was clean and free from any organic impurities some of its essential physical properties obtain through laboratory test were shown in fig 3.2. Sieve analysis performed on fine aggregate and coarse aggregate are displayed in figure 3.3. The water absorption, density and specific gravity of sand were determined as per ASTM C128.

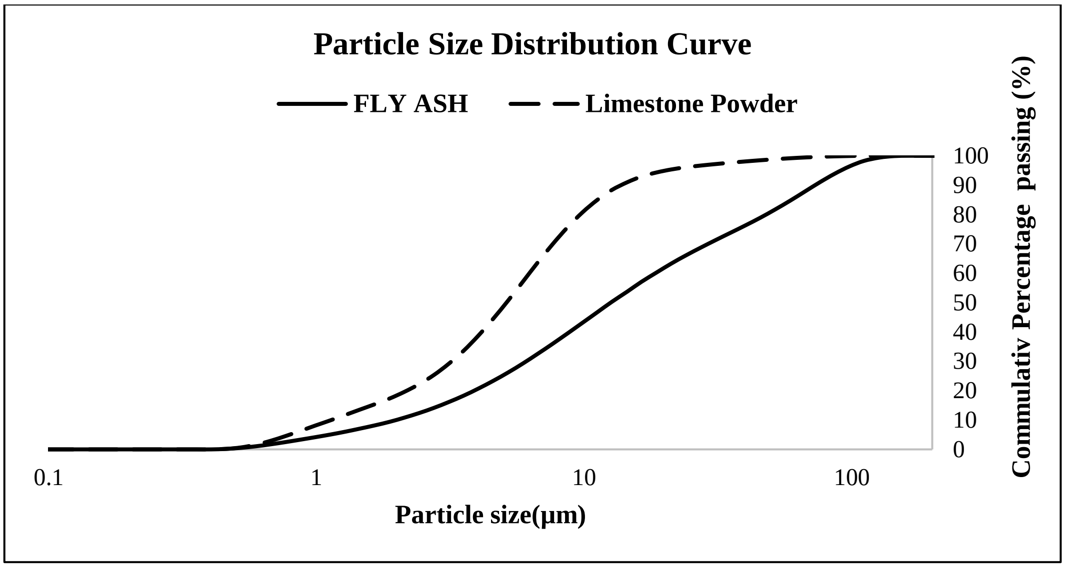


Figure 3-1: Particle size distribution of LSP and FA

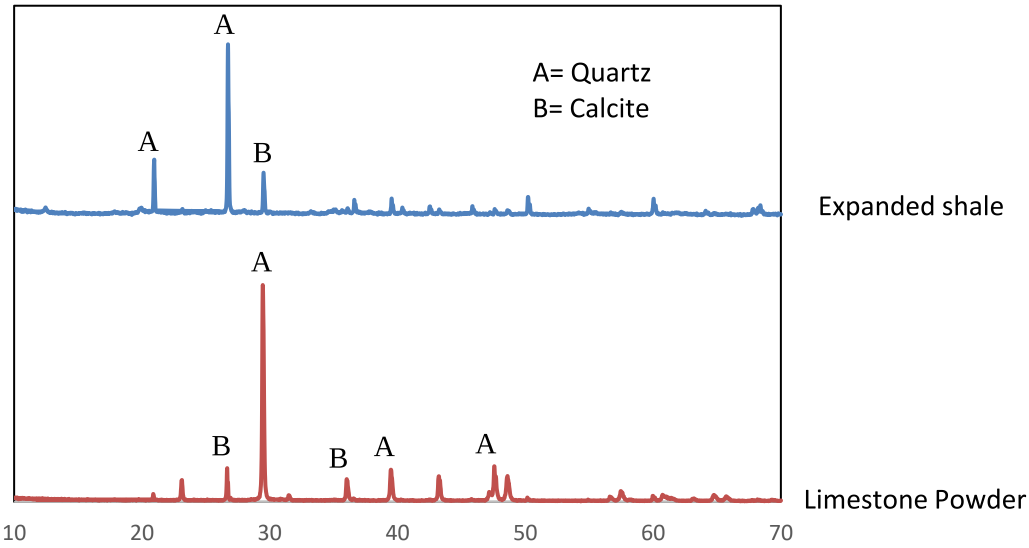


Figure 3-2: X-ray diffraction pattern of expanded shale and Limestone powder

Table 3-2: Physical Properties of Fine and Coarse Aggregate.

S.NO	Properties	Results			
		Coarse Aggregate (8-16) mm	Coarse Aggregate (2-8) mm	Fine Aggregate	Lightweight Aggregate
1	Max aggregate size (mm)	16	8	2	16
2	Fineness modulus	6.82	5.82	2.24	6.9
3	Specific Gravity (SSD)	2.44	2.47	2.78	1.64
4	Water Absorption (%)	0.7	0.5	1.62	5.02
5	Crushing (%)	21.63	26	_----	39
6	Rodded bulk density (Kg/m3)	1775	1597	1635	841.5

Normal weight aggregate comparising of crushed angular stone were obtained from Margalla crush for the current research work. Coarse aggregates were used in two sizes i-e One has 2-8mm and the other one has 8-16mm. The maximum size for the coarse aggregate is 16mm coforming to ASTM C33, in surface dry condition (SSD) with a specific gravity of 2.47 (2-8mm) and 2.44(8-16mm) were used. Some of its physical properties obtained through lab test are listed in figure 3.2. Test result of aggregate gradation performed on coarse aggregate is shown in the figure 3.3 . The water absorption , density and specific gravity of the coarse aggregate were determined as per ASTM C127.

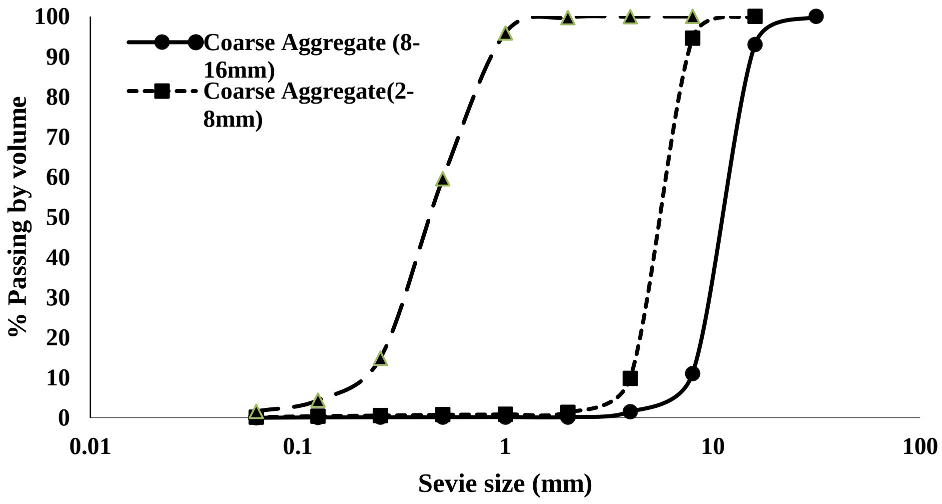


Figure 3-3: Sieve analysis of coarse aggregate and fine aggregate

For the current researchwork lightweight aggregate were made bloated shale. The bloated shale aggregate was obtained by expanding clay pellets of varying sizes by heating them upto a temperature of about 1140 ℃ in the rotary kiln available in PCSIR laboratories, Peshawar, Pakistan. Chemical properties of lightweight Aggregate is analyzed throught XRF spectroscopy and some of its essential physical properties obtained through laboratory tests are presented in a table 3.1 and figure 3.1.

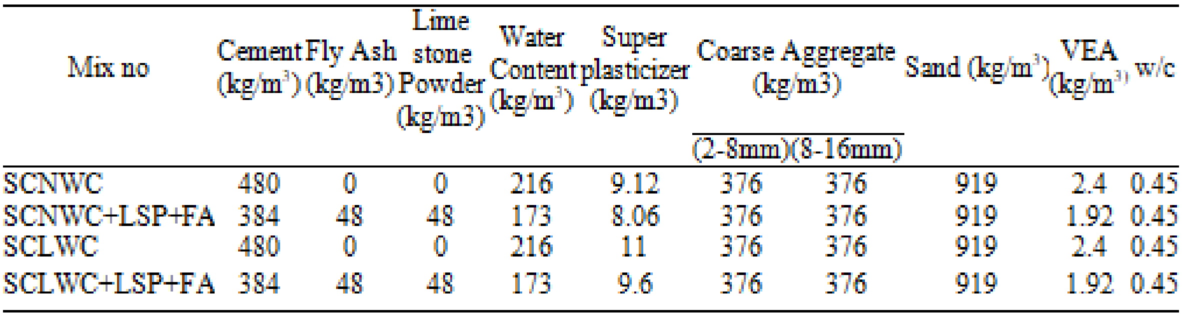
As far artificial lightweight aggregates are concerned, the expanded shale is one of the commonly used material in lightweight concrete production. Its use has increased worldwide due to its production technique improved, mix design, placement methods and air entrained.

Most manufacturing processes for lightweight aggregate; either rotary kiln or sinter strand (sintering method) is used except the manufacture of blast furnace slag. Expanded shale can be formed by heating the suitable shale to the point of melting. The finished product is highly cellular aggregate. Burning takes place in rotary kiln under controlled temperatures ranges from 1000oC to 1200oC.

3.2 Mix proportion and mixing procedure

The SCC mix composition were designed by following the guidelines of EFNARC 2005 and ACI 237R-07. In this research several trail concrete mixes using normal weight coarse aggregate and lightweight coarse aggregate with different superplasticizer dosages.From the numerious trail concrete mixes,suitable mixes satisfy the different workability tests i.e.(J-ring test, Slump flow test, V-funnel test, L- box) tests were selected. A four formulation one has Simple SCC(control mix), second formulation contain (Control mix+LSP+FA), the third formulation is self consolidating lightweight Concrete(SCLWC) and fourth formulation was (SCLWC+LSP+FA). The water to cement ratio (w/c) was kept constant for all formulation i.e. 0.45 . The ratio of coarse to fine aggregate was 50:50. The mix proportion of various SCNWC and SCLWC mixes are shown in the table.

Table 3-3: Mix proportion of Concrete (kg/m3)



Mix no	Cement (kg/m^3)	Fly Ash (kg/m3)	Lime stone Powder (kg/m3)	Water Content (kg/m^3)	Super plasticizer (kg/m3)	Coarse Aggregate (kg/m3)		Sand (kg/m^3)	VEA (kg/m^3)	w/c
						(2-8mm)	(8-16mm)			
SCNWC	480	0	0	216	9.12	376	376	919	2.4	0.45
SCNWC+LSP+FA	384	48	48	173	8.06	376	376	919	1.92	0.45
SCLWC	480	0	0	216	11	376	376	919	2.4	0.45
SCLWC+LSP+FA	384	48	48	173	9.6	376	376	919	1.92	0.45

The sequence and duration of the mixing is very vital in the making of SCNWC and SCLWC, as they influence the workability of concrete. High Performance Pan mixer at NICE, National University of Science and Technology (NUST), Islamabad developed by PROF Dr .Syed Ali Rizwan was used for concrete mixing as shown in fig 3.4.

Figure 3-4: High performance concrete Pan Mixer

All the material were placed in the Pan Mixer by following the sequence with coarse aggregates being placed first followed by sand and cement to ensure efficient mixing. The following mixing regime was followed for all formulation.

Table 3-4: Mixing regime for all formulation

1 minute	Dry mixing of constituents at 180 rpm (slow rate)
2 minute	Add 80% of water in the dry constituent and mix again at 180 rpm (Slow mixing)
3 minute	Add SP and/or Viscosity Enhancing Agent (VEA) in remaining 20% water; mix again thoroughly at 360 rpm (Fast mixing)

3.3 Test methods performed on fresh concrete

3.3.1 Slump flow

The Slump flow test aim to investigate the filling ability of Self consolidating normal weight concrete and self consolidating lightwieght concrete. Slump flow test is used to measure the flow time and flow spread of self-compacting concrete (SCC). The dosage of superplasticizer (SP) and water/cement ratio play a foremost role in assessing the flow properties of SCNWC and SCLWC. **ASTM C1611** standard offers two cone positioning choices that is, upside-down and downside up. In this research, downside-up. In this research, narrow end up position of slump cone was adopted.

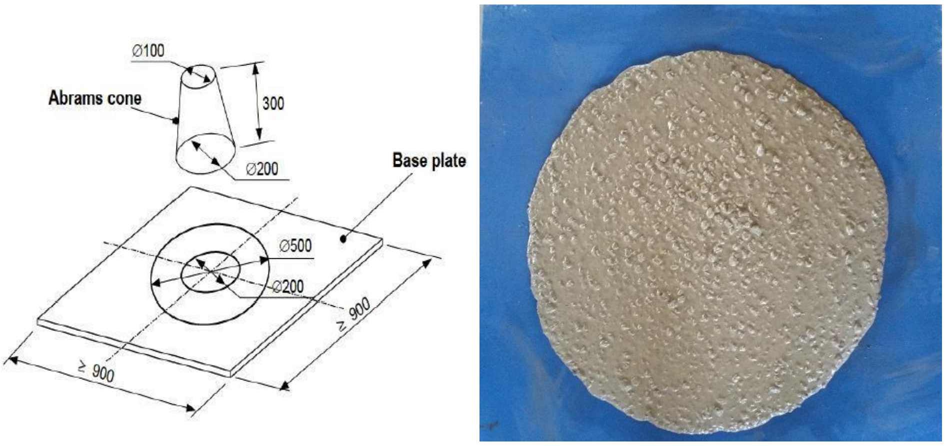


Figure 3-5: Base plate and Cone (left) and Slump flow (right)

3.3.2 V-Funnel Test

V-Funnel test is used to measure the flowability of SCC. It gives the interval required for the concrete to fall under the effect of gravity through a small opening in the apparatus as shown in fig.

To carryout this test, place the V-funnel vertically on a stable and flat level ground, with the top opening horizentally positioned. Wet the inside surface of the funnel using moist sponge or towel. Close the opening at the bottom of funnel and place a bucket underneath it to accumulate the concrete failing from the V-funnel. Fill the funnel completely with freshly prepared concrete without applying any tamping. Then after interval of 10±2 seconds, open the gate or opening the bottom of the funnel. Measure time from unfastening of gate of sign of viewing the first light from underlying opening. The timer reading thus noted is referred as V-funnel flow time, and expressed to the closest 0.1 seconds.

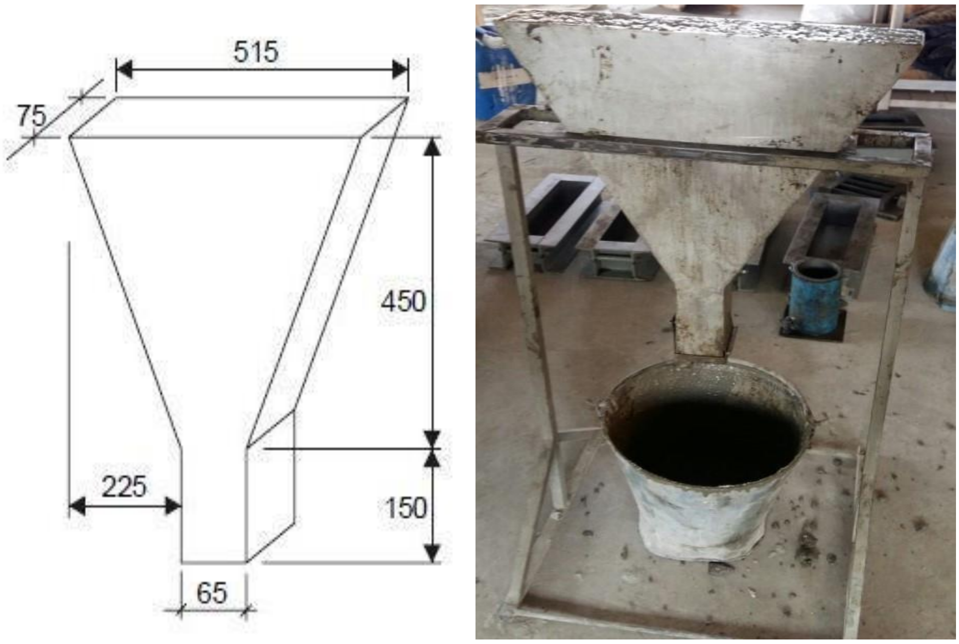


Figure 3-6: V-Funnel Apparatus

3.3.3 L-Box Test

The L-box test method is used to investigate the passing ability of SCNWC and SCLWC through reinforcement. It measures the reched hight fo fresh concrete after passing through the specified gaps of steel bars and flowing within specified distance. The behaviour of SCNWC and SCLWC regarding its passing ability can be observed througth this reached height.

In this test, two types of gates having 12 mm diameter bars can be utilized. One gate contain 3 bars with 41 mm opening while the other one has 2 bars with 59 mm opening. Position the L-Box vertically on a hard and level surface. Close the sliding gate and fill the vertical part of L-Box fully with concrete without any compaction. Allow the concrete to remain undisturbed in L-box's vertical part for a 1 minute (± 10 seconds) so that the constituents of concrete get adjusted. Determine time from fully rising of the sliding gate and the concrete flowing from L-box's vertical part and reaching to the points 200mm, 400mm and 600 mm in its horizontal part. Also determine the heights H1 and H2 after flow is ceased.

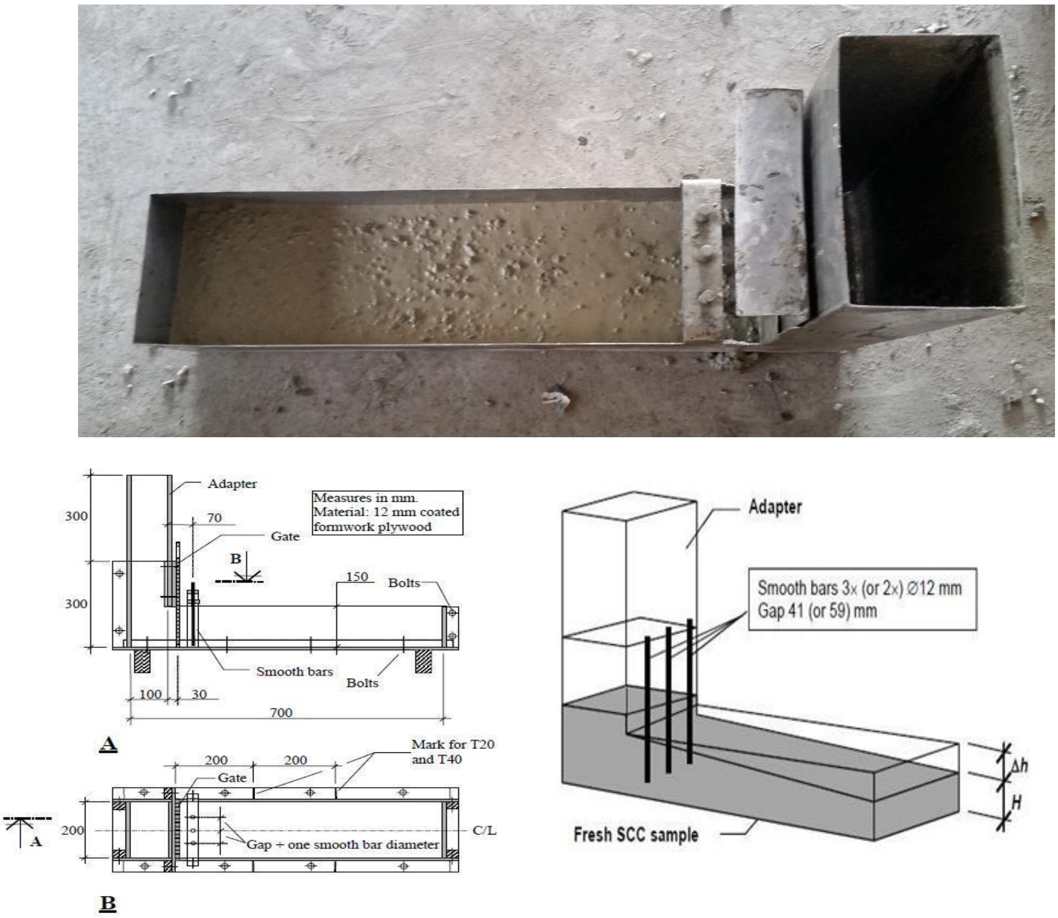


Figure 3-7: L-Box Test (top) and Apparatus (down)

3.3.4 J-Ring Flow Test

This test is described in ASTM C1621. This test is used to measure the passing ability of self compacting concrete (SCC). In this test, a ring having steel bars, called J-Ring is placed around the slump flow cone for checking passing ability.

The same procedure is applied in J-Ring as slump flow test, only the difference is the J-Ring is placed on the base plate around the cone i.e after the cone is lifted, T50 time and concrete J-ring flow spread after passing through j-ring must be measured in orthogonal directions, J-ring flow is the average of two diameters measured in orthogonal directions.

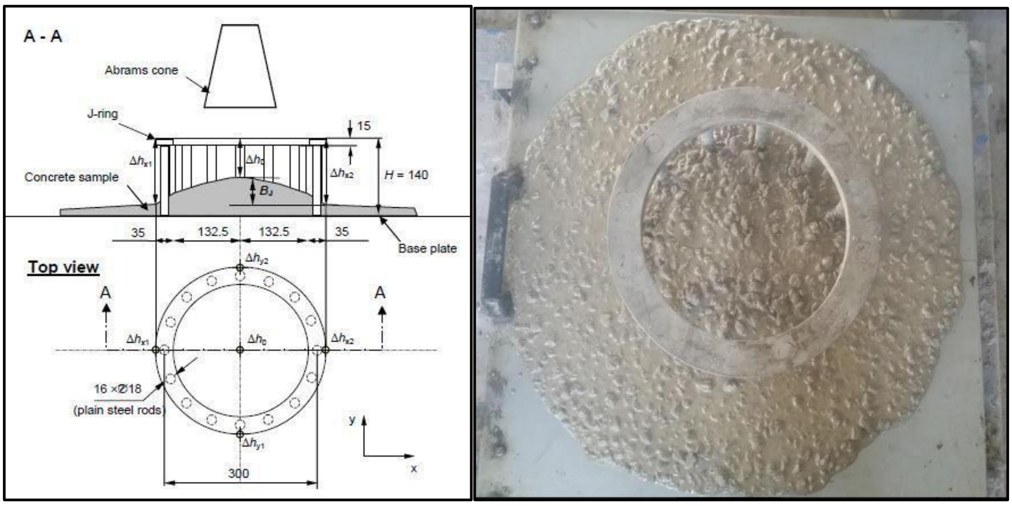


Figure 3-8: J-ring Apparatus (left) and J-Ring flow (right)

3.4 Test on fresh and Hardened SCNWC and SCLWC

3.4.1 Density of Fresh SCNWC and SCLWC

The density of fresh concrete is determined by measuring the weight of container of known volume, fully filled with fresh concrete. The weight divided by the volume gives the density of fresh concrete.

3.4.2 Air Content of Fresh SCNWC and SCLWC

The air content in freshly mixed self-compacting concrete is measured by following the standard ASTM C231 and EFNARC 12350-7 guidelines.The pressure method is used to determine the air content in concrete. Pressure meter container of known volume is filled with fresh SCC and container’s upper surface must be leveled using a straint edge. Place the pressure meter lid on the container and measure the air content on the measuring guage.

Figure 3-9: Air Content Apparatus

3.4.3 Flow Test Sequence for Self –Consolidating Concrete

After the first mixing of SCC, test were carried out in the following sequence as described below

- Slump flow
- V-funnel
- L-Box
- J-Ring
- Seive Stabililty Test (Segregation resistance)

The average time spent on completing the flow tests was around 20 minutes by four member's party. In laboratory, the sample was agitated again for 5 seconds each before starting some other flow test after the slump test.

3.4.4 Acceptance Criteria for SCNWC and SCLWC

The fresh properteis of SCNWC and SCLWC according to EFNARC 2005 guidelines is shown in fig below

Table 3-5: Acceptance Criteria for fresh properties of SCNWC and SCLWC

SN	**Method**	**Unit**	**Typical range of Units**	
			Minimum	Maximum
1	Slump flow by Abram's Cone	Mm	650	800
2	T50 cm Slump flow	Sec	2	5
3	J-Ring	Mm	0	10
4	V-Funnel	Sec	6	12
5	L-Box	H_2/H_1	0.8	1
6	GTM screen Stability Test	%	0	15

3.4.5 Casting and Curing

The casting, curing and testing were carried out as per EN 196-1. Concrete were cast in to moulds of three samples for each formulation and for each age of concrete (3,7,14 and 28 days). Cylinders of 150x300 mm^2 and a beams of 150x150x750mm^3 were casted for each formulation of SCNWC and SCLWC as per guidelines of (BS EFNARC 12390-1). A total of 48 cylinders, 8 beams were casted for all four formulations.

The casted samples were demoulded after 24 hours and till the require testing age they were placed in the curing tank, which contained water at the controlled room temperature.

3.5 Testing of the Specimen

3.5.1 Flexure Strengh Test

For measuring fracture properties of concrete in term of pre crack and post crack responses, concrete beams of dimension of 150mmx150mmx750mm cured for 28 days were tested using strain conctrolled SHIMADZU Universal Testing Machine (UTM) of 20KN capacity test performed in Institute of Space technology(IST), Islamabad . The specimen were tested in 3 point bending were performed. The test was performed to find maximum value of stress at the centre because the load is acting there. The specimen were then tested at strain rate affixed at 0.01mm/sec as per ASTM C293 to sensitivity capture the inititaion and propagation of cracks. The specimen were placed in the frame to act as simply supported with clear span of 600mm. Test arrangement made for 3-point bend test is shown in the figure 2.10.

Figure 3-10: Flexure test setup (three-point bend test)

3.5.2 Water absorption and Density

Water absorption of concrete sample at the age of 28 days and density of SCNWC and SCLWC and the other two with limestone powder and flyash in its hardened state were studied as per the standard set forth by ASTM C642. Water absorption of concrete specimen were measured as a percentage difference in the weight of concrete samples before and after the immersion in water at the age of 28 days, while density of both SCLWC and SCLWC samples containg limestone powder and flyash were measured in hardened state is shown in table 4.1.

3.5.3 Compression Test

To access the compression strength of both SCNWC and SCLWC with replacement of limestone powder and flyash, cylinderical specimen with dimension of 150mmx300mm cured at 3, 7, 14 and 28 days were tested in compression using SHIMADZU Universal testing machine (UTM) at a loading rate of 0.2 MPa per second as per ASTM C39. Fig shows test arragement made for measuring compression strength of concrete samples. The data is shown in figure 4.11

3.5.4 Microstructure of SCNWC and SCLWC

For SEM, samples of both SCNWC and SCLWC after compression testing were selected to study the microstructure, morphology and ITZ formation. The sample preparation for both the tests were done in the laboratory by placing sample in Isoproponol for 24 hours after testing of cylinder after 28 days in compression to stop hydaration. The Sem were done in Nust, Islamabad.

Figure 3-11: Sample for SEM

CHAPTER 4

4 RESULT AND DISCUSSION

This chapter comprises of water absorption, density, flexural strength, compression strength, microstructure analysis, and FTIR anaylys of both SCNWC and SCLWC concrete with both having replacement of limestome powder and flyash.

The fresh properties of SCNWC and SCLWC with replacement with limestone powder and flyash and different superplasticizer demand were studied. The fresh properties results of SCNWC and SCLWC are mentioned in tablular form in the table.

Table 4-1: Fresh properties of SCNWC and SCLWC

Fresh properties of SCNWC and SCLWC

Mix	Fresh Density (kg/m^3)	Sp demand (%)	Slump flow (mm)	Slump flow time (sec)	V- funnel flow time (sec)	L-box (H2/H1)	J-Ring Flow (mm)	J-Ring Blocking step (mm)	Segregation resistance (mm)
SCNWC	2338	1.4	720	2.2	9.6	0.86	700	6	9.73
SCNWC+LSP+FA	2342	1.8	740	2.5	10.28	0.83	720	7	9.51
SCLWC	1798	1.2	730	2	9	0.8	710	5	9
SCLWC+LSP+FA	1802	1.6	750	2.3	9.7	0.82	730	6.7	8.7

4.1 Super Plasticizer demand for SCNWC and SCLWC

The superplasticizer demand for all the four formulation with water to cement raio(w/c) of 0.45, having a target flow of 70±2 is shown in fig below. SCNWC requires 28.17% more superplastizer(SP) than SCNWC+LSP+FA . while SCLWC requires 14.28% less SP than SCNWC which is control mix. This is due porous structure of lightweight aggregate. While SCLWC+LSP+FA require 33% more SP than SCLWC.

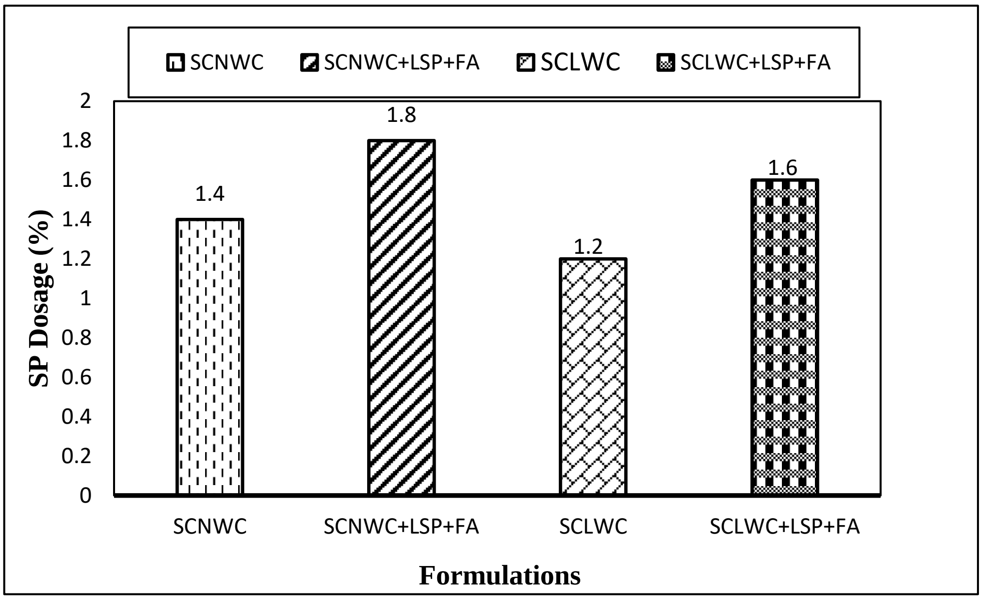


Figure 4-1: Super plasticizer demand

4.2 Slump Flow Spread Test of SCNWC and SCLWC

The total spread (flow) for all the formulations under constant w/c ratio of 0.45 is shown in fig whereas the flow time (T_{50}) for 500 mm is shown in fig

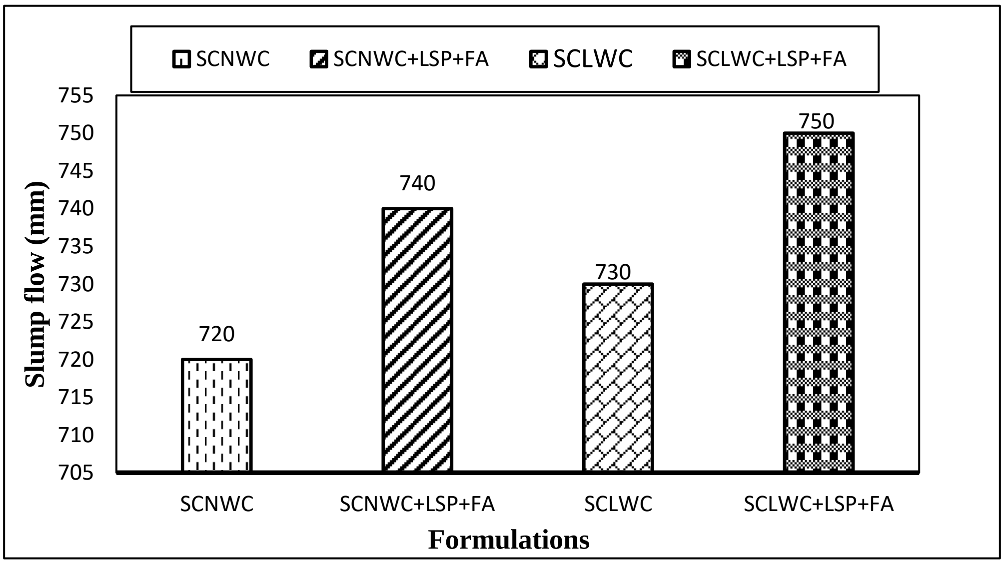


Figure 4-2: Slump flow

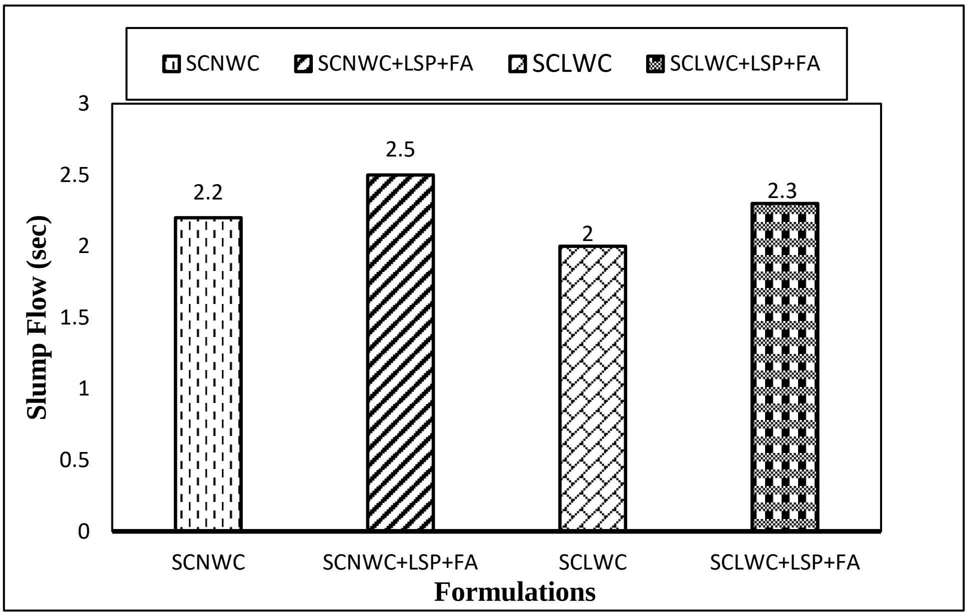


Figure 4-3: Slump Flow time

All the values of slump flow and T_{50} are satisfactory and within acceptable range of SCNWC and SCLWC for a slump flow i.e.(720-750mm) and the flow time (2-5 sec) respectively. Although it can be observed that slump flow increases when lightweight aggregate is used. This is due to its round shape and circular nature. In the Slump flow spread SCNWC+FA+LSP has 3% more flow than SCNWC. This is because of the addition FA and LSP which enhance the flow. While the SCLWC+LSP+FA has the greatest flow, and 4% more than control mix (SCNWC). While SCLWC has slump flow of 1.3% more than SCNWC. This is because of the porous nature of lighweight aggregate and round shape of lightweight aggregate.

4.3 V-Funnel Flow Time of SCNWC and SCLWC

The V-funnel flow time for all the formulation under constant w/c ratio of 0.45 is shown in the figure 4.4.

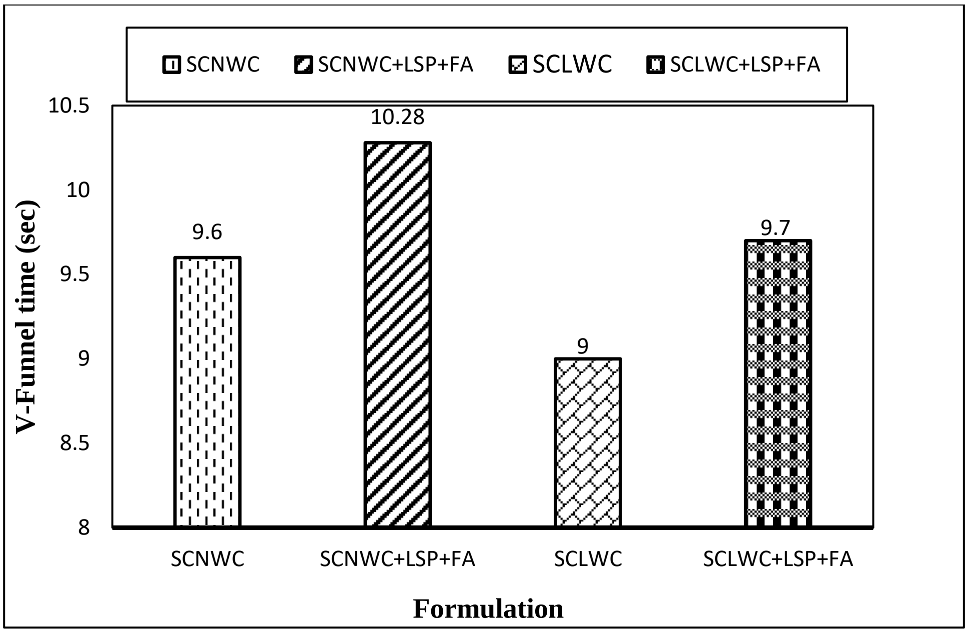


Figure 4-4: V-Funnel flow time

All the values of V-funnel flow test is within the acceptable limit i.e (6-12sec). V-funnel flow time indicate viscosity, which depend upon the type of aggregate used. V-funnel flow time for SCNWC+LSP+FA is greater than all. It is 7 % than the control mix this is due to the secondary raw materials. While V-funnel flow for SCLWC 6% less than control mix. This is due to lightweight of aggregate and due to its porous nature.

4.4 L-Box Test of SCNWC and SCLWC

In the L-Box test the height diffrence (H_2/H_1) on both sides for all formulations of SCNWC and SCLWC are shown in the figure 4.5

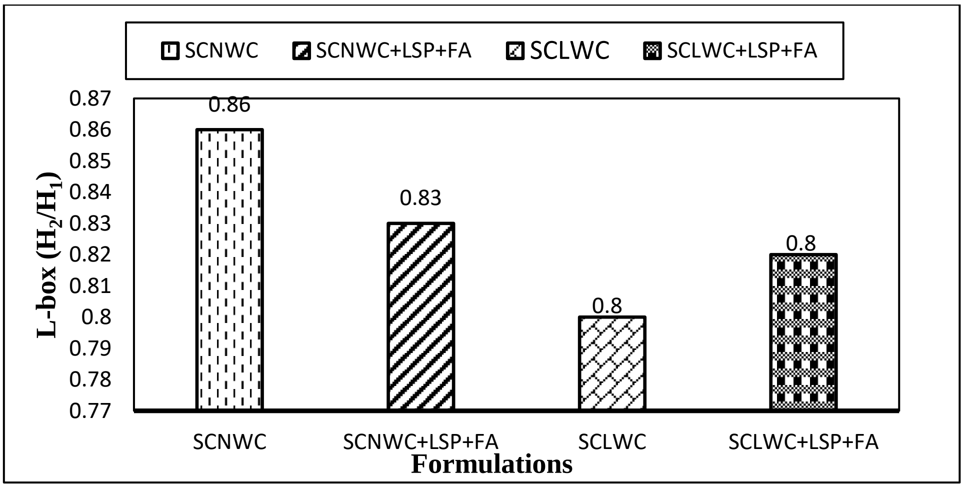


Figure 4-5: L-Box (H2/H1)

L-box test results are within the acceptable limits of SCNWC and SCLWCi.e. (0.8-1.0). Lower value of H2/H1 shows lesser passing ability of concrete through L-box. Also the aggregate size effects the passing ability which stuck off between steel rods, reduces the passing ability. Replacement of normal aggregate by lightweight aggregate increases the passing ability and decrease the blocking tendency of mix due to its round and regular shape and texture. Due to no interlocking of lightweight particles, L-box flow time also decreses with use of lightweight aggregate. The the control mix has the great hight differecnce. This is probaly due to high SP demand. While the SCLWC has 7% less value than SCNWC. This may due to its porous nature of aggregate and better flow.

4.5 J-Ring Flow Test of SCNWC and SCLWC

The J-Ring flow and blocking index Bj for all four formulations of SCNWC and SCLWC under a constant w/c ratio i.e. 0.45 are shown in figure 4.6 and 4.7.

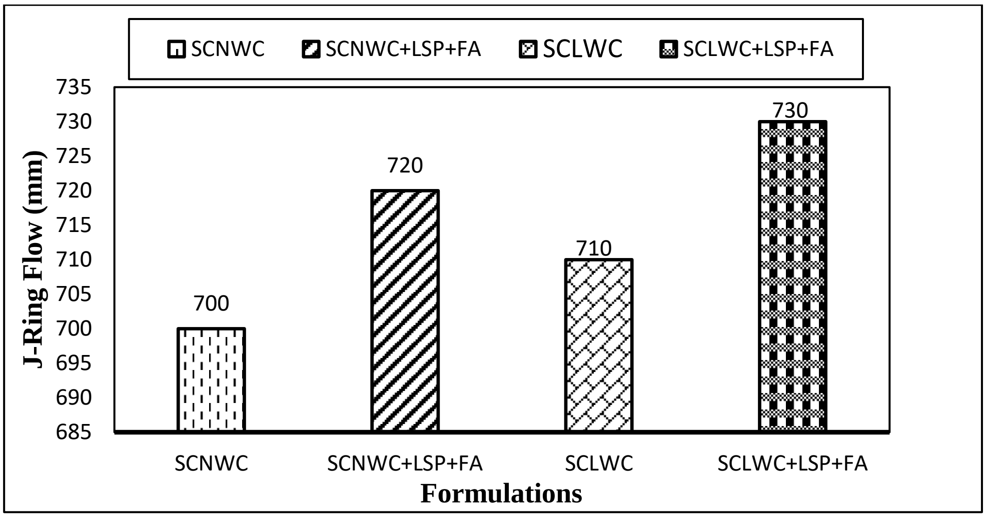


Figure 4-6: J-Ring Flow

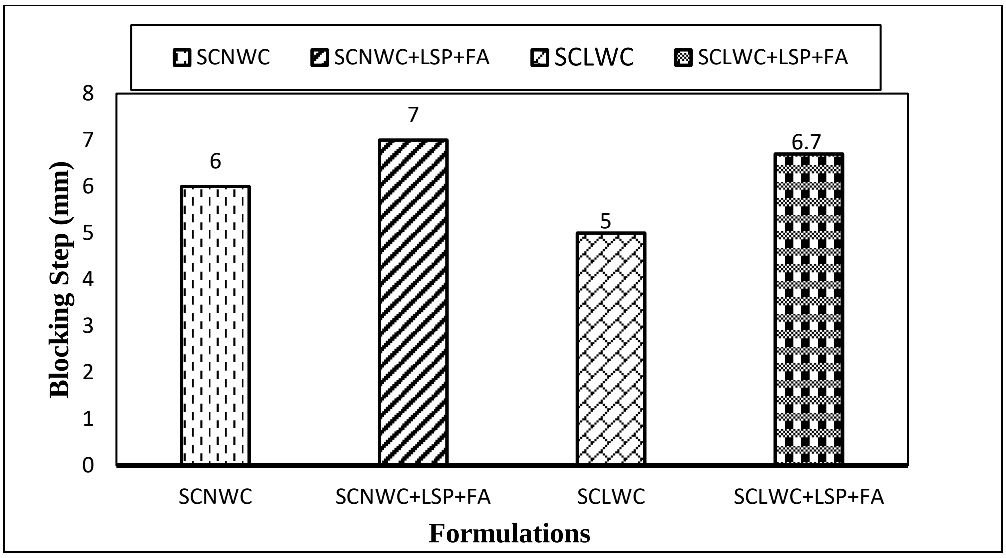


Figure 4-7: J- Ring blocking steps

All the J-Ring flow and blocking step B_J values are satisfactory and within the acceptable range of SCNWC and SCLWC. J- ring test measure the passing ability of concrete through steel rods. Literature suggests that the difference between slump flow and J-ring values should be less than or equal to 50mm for SCNWC and SCLWC for the better passing ability(Refrence from memon thesis). It has been observed that J-Ring flow values increases with the use of lightweight aggregate this may be due to better bonding and with constant w/c ratio i.e. 0.45. The J-Ring flow for SCLWC+LSP+FA has the most and it is 4.10% more than control mix due to the round shape of aggregate and light weight of aggregate.

4.6 Fresh density and Air content of SCNWC and SCLWC

The fresh density and air content of SCNWC and SCLWC under contant w/c ratio of 0.45 are shown in figure 4.8 and 4.9.

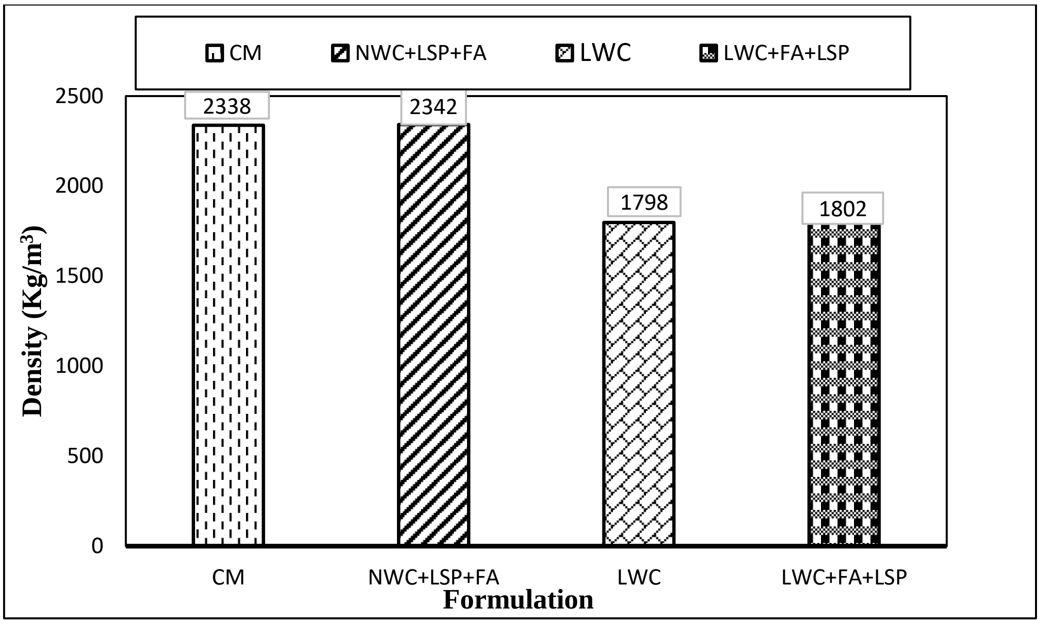


Figure 4-8: Fresh densities of different formulations

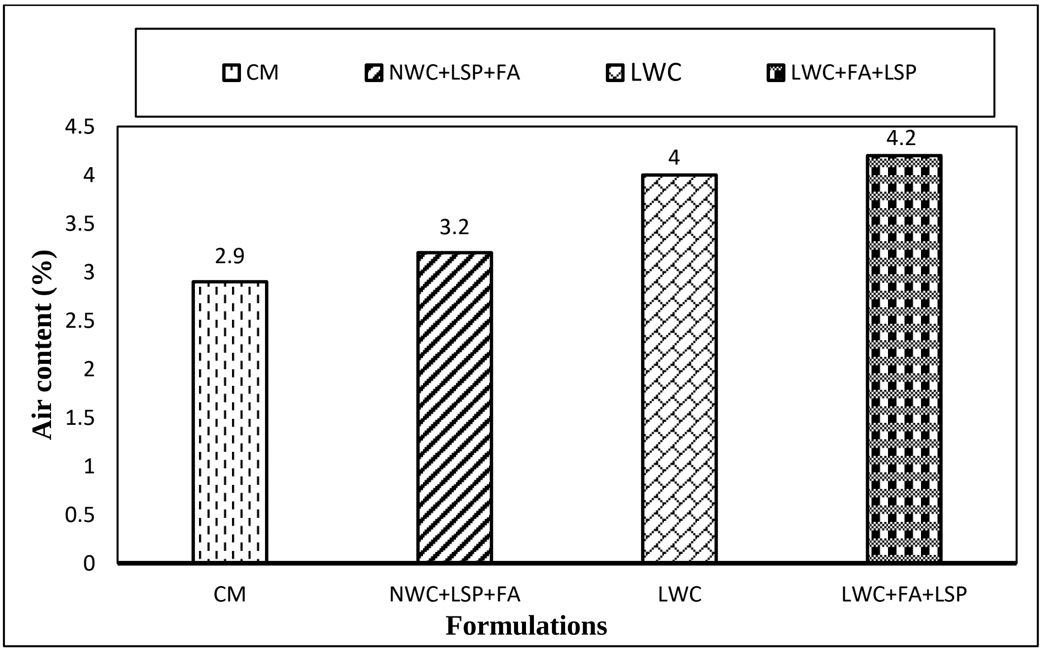


Figure 4-9: Air content of different formulations

The fresh densities of NWC increses with addition of admixture i.e lime stone powder and flyash. The densities of lightweight aggregate is less than normally used i.e (lime stone) coarse aggregate. It slightly increases with increase in admixture but in acceptable range. The fresh density for SCLWC show much better response than SCNWC. The SCLWC has density of 30% less than SCNWC.While SCLWC+LSP+FA has 23% less density than control mix. This is due to the porous nature of aggregate and lightweight also.

4.7 Fracture Properties of SCNWC and SCLWC

4.7.1 Stress strain Response in Flexure

The stress-strain response of SCNWC and SCLWC specimen in flexure with the addition of limestone powder and flyash is presented in the fig

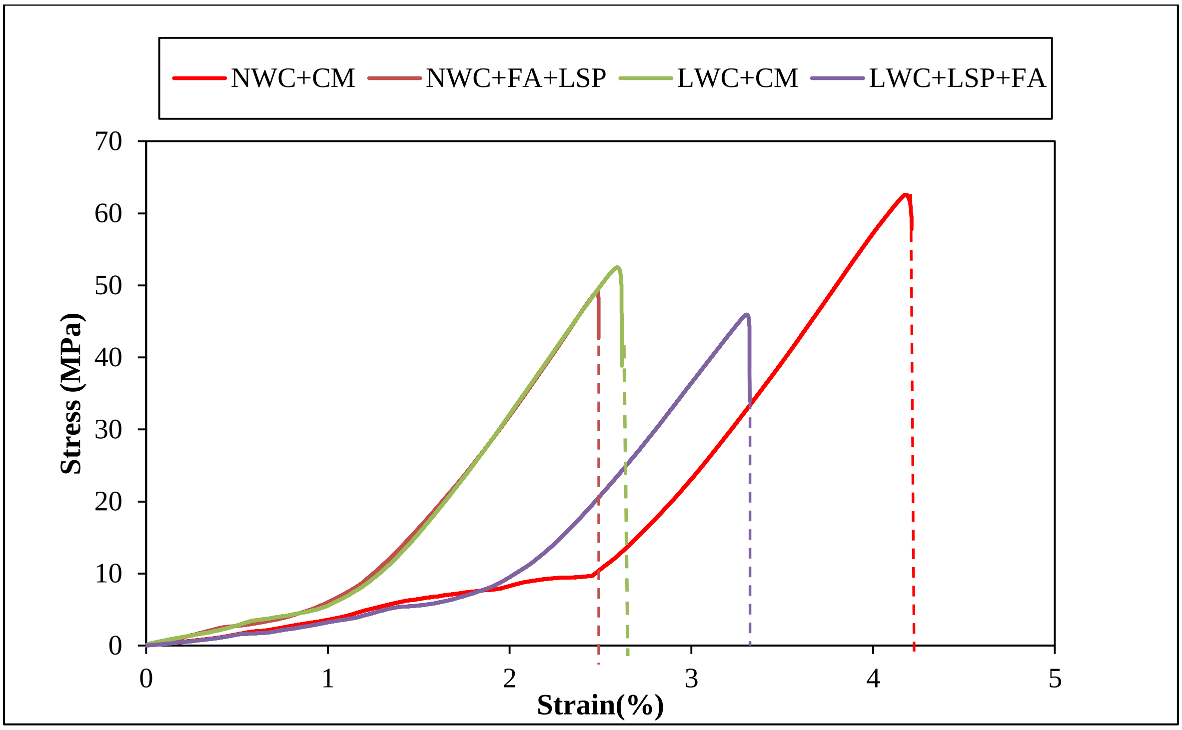


Figure 4-10: Flexural response of SCNWC and SCLWC

The flexural strength of control mix is greater than all. But the addition of SRMs will decrease its flexural strength as well as its stability which is also less than SCLWC. While the SCLWC control mix show better durability with appreciable flexural strength.

The flexural strength of control mix is 16% more than SCLWC. The modulus of elasticity for SCLWC is less than control mix. This is due to its better bonding and appreciable strain in stress strain curve.

Table 4-2: Flexural Properties of SCNWC and SCLWC

Denotation	Modulus of Elasticity (MPa)	Flexural Strength (MPa)	Ultimate strain (%)	Toughness ($J.m^{-3}$)
SCNWCs	13.9	62.54	4.174	73.12
SCNWC+LSP+FA	6.82	49.16	2.482	39.78
SCLWC	12.65	52.5	2.594	46.00
SCLWC+LSP+FA	7.62	45.94	3.304	42.05

4.8 Compressive Strength of SCNWC and SCLWC

The compressive strength of SCLWC at 28 days is (2-4%) less than that of SCLWC and this is due to the round nature of aggregate which shows better resistance. For typical lightweight concrete, the compressive strength decreases with a decrease in density.

The figure 4.11 shows the change of compressive strength of SCNWC and SCLWC with respect to age. The compressive strength of SCNWC and SCLWC increase from 25 to 41 MPa and 23 to 40 MPa respectively. The mix design for SCLWC and SCNWC targets the same compressive strength. One can get SCLWC of the same quality as normal SCC, if the appropriate amount of SP, VMA and lower water binder (w/b) is used. Due to the replacement of cement with FA and LSP the compressive strength increases, this is due to the pozzolanic and filler effect which is provided fly ash. The w/c ratio played a significant role in enhancing the 28-day compressive strength and the pore structure of SCLWC. The homogeneity and unit weight of SCLWC also depend upon the w/c ratio. The ratio of water to cement and lightweight aggregate content in the mixture shows the similar positive effect on the compressive strength of SCLWC. Improving effect of lightweight aggregate on the compressive strength are more than normal weight coarse aggregate.

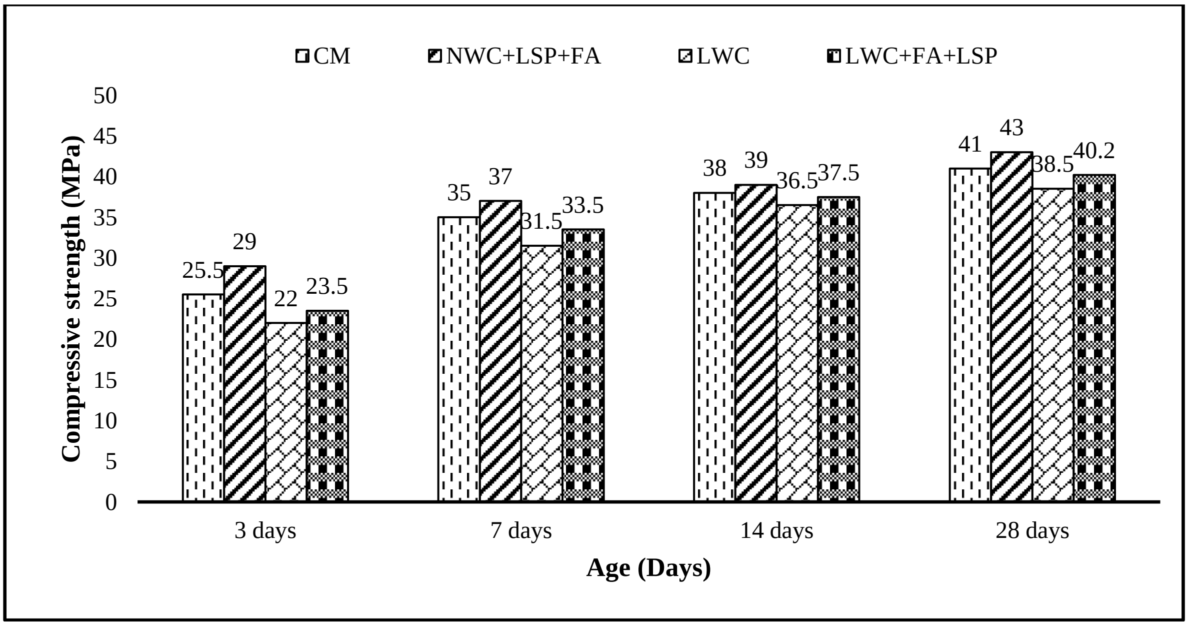


Figure 4-11: Compressive strength of SCNWC and SCLWC

The compressive strength at 28 days of SCNWC is approximately same as that of SCLWC and this is due to the round nature of aggregate which show better resistance.

4.9 Microstructure of SCNWC and SCLWC

4.9.1 Microstructure by SEM

Samples of both SCNWC and SCLWC after compression testing at 28 days age were selected to study the microstructure and morphology.

The figure 4.12 to 4.16 shows the morphology of the four formulations. The SEM of the different concrete formulation was done from which one can find out the porosity, pore size and internal and external shape of lightweight aggregate. The pozzolanic activity will increase the hydration reaction and microstructure of concrete, which in term enhance the durability of SCLWC.

The SEM images, in order to study the effect of replacement of the cement with FA and LSP, there is the effect on the mechanical properties of SCNWC and SCLWC. This is because of the pore size and cellular structure of lightweight aggregate. The FA and LSP particles will induce in the honeycomb-like porous lightweight aggregate and this phenomenon will increase the compressive strength of the overall mixture. Fig below represent SEM picture of SCNWC and SCLWC respectively.

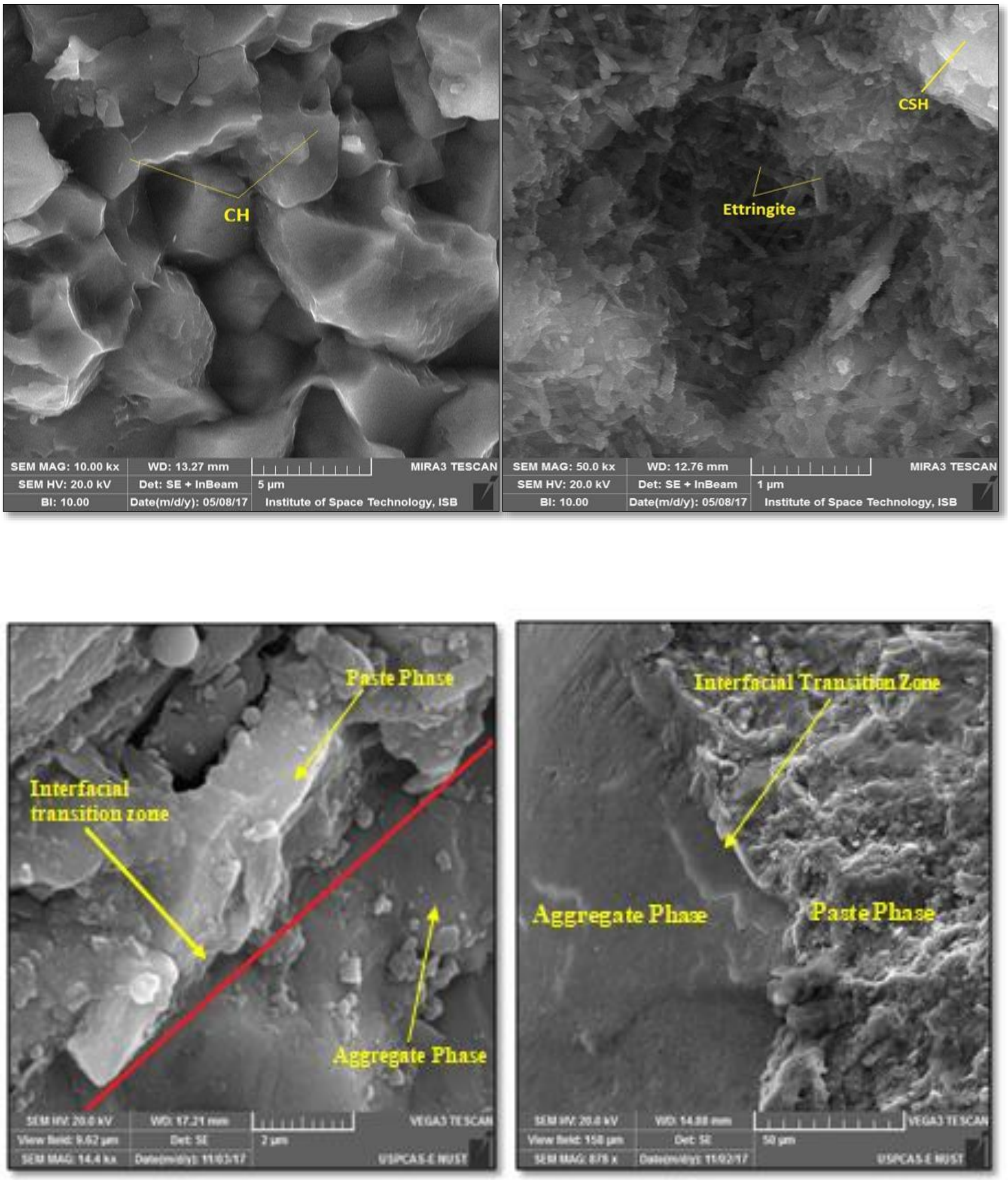


Figure 4-12: SEM of SCNWC

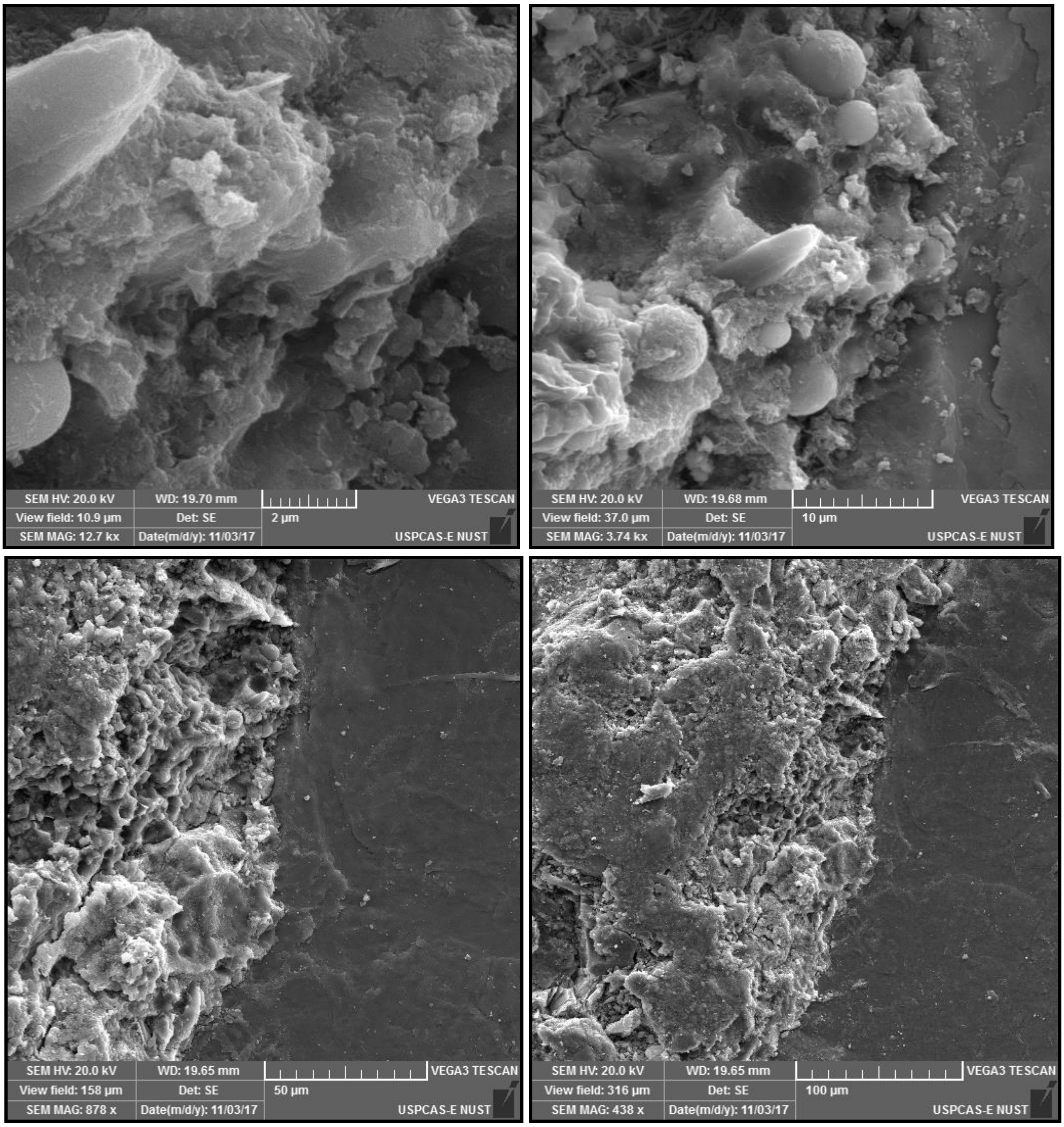


Figure 4-13: SEM pictures of LSP-FA-SCNWC

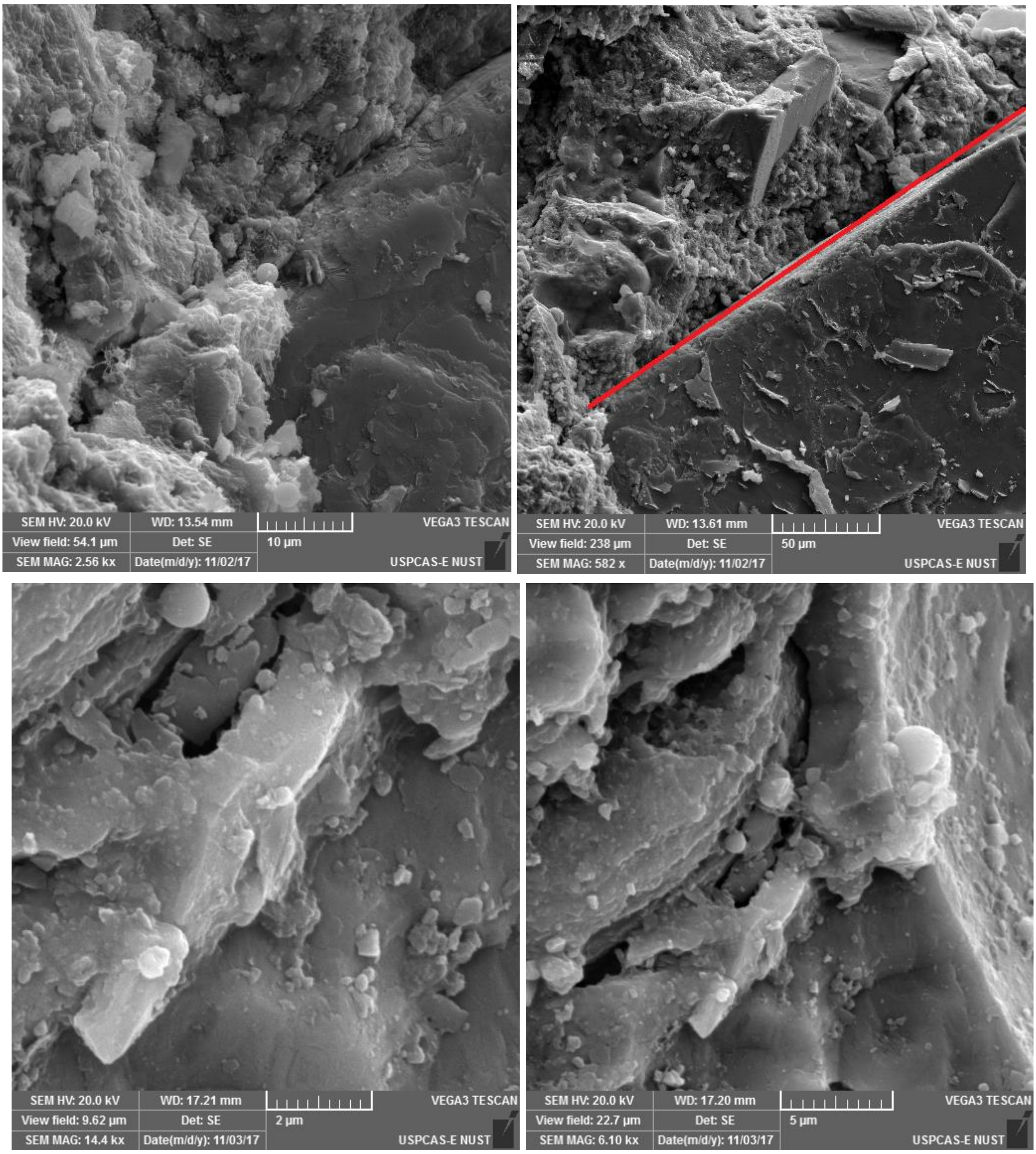


Figure 4-14: SEM of SCLWC

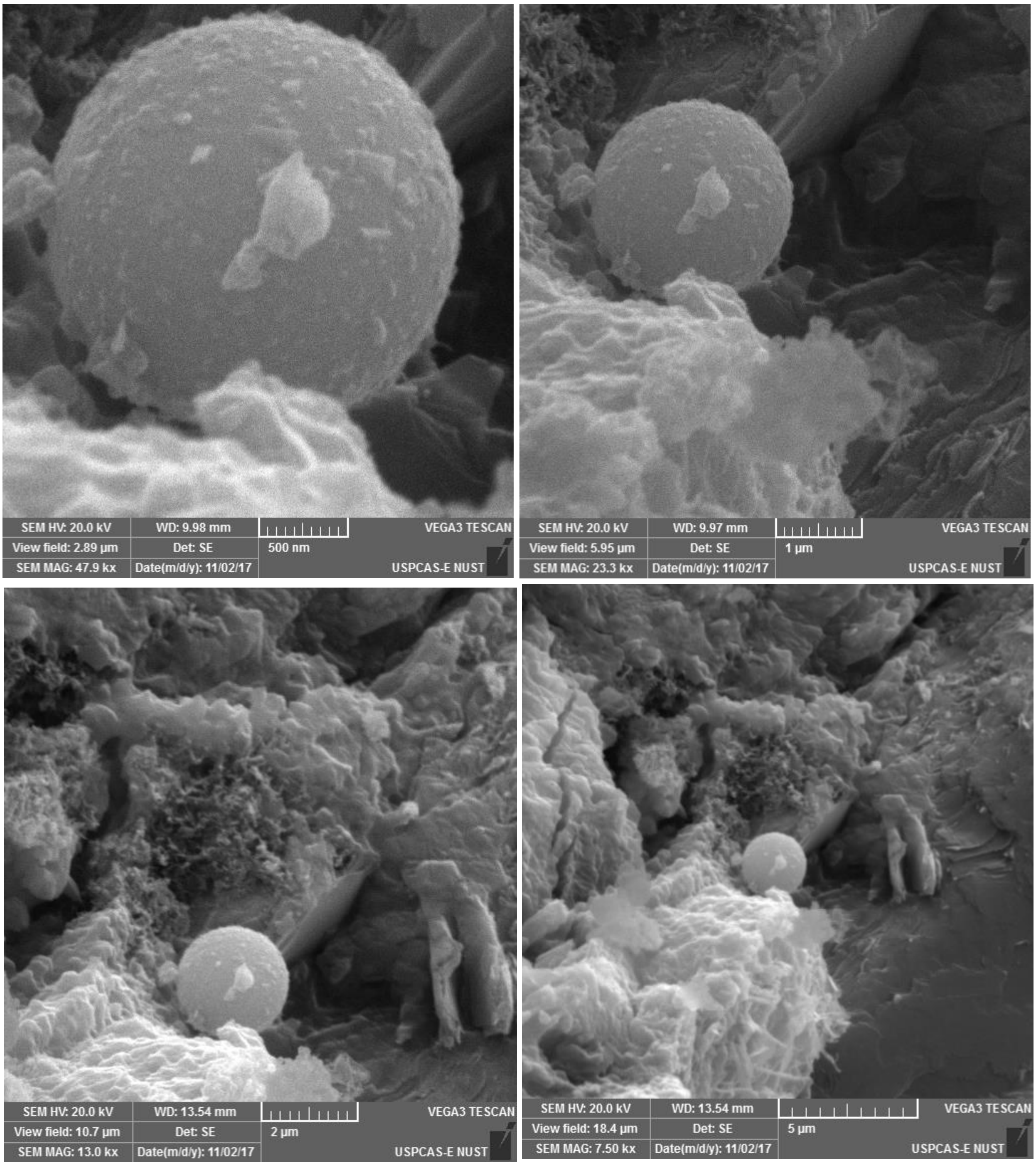


Figure 4-15: SEM of LSP-FA-SCLWC

4.10 Summary of the Results

Based on the result and observations of an experimental investigation of fresh and hardened properties of SCNWC and SCLWC, the following conclusion are drawn from this study.

1. Chemical analysis of shale taken from Nust, Islamabad show that almost all the shale deposit in Nust, Islamabad are bloatable because it contain iron content more than 8.5% by weight. Proper pelletizing of clay was found to be essential for the efficient production of high-quality lightweight shale aggregate.

2. While Preparing Lightweight Shale Aggregate (LWSA) , it was observed that a proper slope of rotary kiln plays a vital role in the production of good end material. The reason perhaps was that at temperature 1140°C , was in complete or partially fused state and in the absence of proper slope, the material stick together and in spite of best mutual efforts it was very difficult to control it. But with proper slope it the material indicate very good bloatability with end product of very less water absorption.(upto 5% by weight)

3. While preparing Bloated Shale Aggregate (BSA) its bulk density was observed between 930 kg/m^3 to 990 kg/m^3. Therefore BSA comes well in the range of LWA. The difference in the bulk density while preparing, it was perhaps due to the difference of bloatability in the different batches or due to different grading or due to both of these reasons.

4. The density of SCLWC was nearly 1798 kg/m^3 with compressive strength 40 MPa and 2238kg/m^3 of SCNWC(control mix) with compressive strength of 41 MPa at 28 days. The most efficient is the density of SCLWC which is about 40% less than SCNWC. This is due to the lightweight of aggregate. The bulk density of SCLWC is about 1700-1750 kg/m^3 which is about 35-40% less than SCNWC. From this result we can conclude that SCLWC is truely structural lightweight concrete.

5. The 28 days compressive strength of SCLWC were 40 MPa, which is similar to SCNWC. The LWAC with fly ash as admixture increases the compressive strength of the concrete. Higher strength was achieved for 10% cement replacement by fly ash. The optimum cement replacement by fly ash is around 10% - 20%. The 28 days

compressive strength of SCLWC is quite similar with SCNWC. The water-cement ratio is kept constant and is 0.45. The higher compressive strength of lightweight aggregate is due to its round shape.

6. The results show that modulus of elasticity of SCLWC is in an acceptable range. The E-value (modulus of elasticity) for the SCLWC is about 37% of that of SCNWC at the age of 28 days. The modulus of elasticity decreases by incorporating fly ash and limestone powder. The values comes well in the range of acceptable international structural lightweight and normal weight concrete.

7. Due to the acceptable workability with medium water to cement ratio in SCLWC, there is no segregation or floating. This is because of the porous structure of lightweight aggregate.

8. Both the admixtures (FA and LSP) has enhanced the compressive strength up to a certain limit. The proper replacement of FA and LSP will enhance the fresh and hardened response of the system.

CHAPTER 5

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

- There is no significant (2-4%) reduction in the compressive strength of SCLWC while 16.1% reduction in flexural strength is noted. Lightweight aggregates tend to shift concrete behavior from ductile to a brittle causing reduction in flexural strength.
- Incorporating the blend of Flyash and Limestone powder has enhanced the compressive strength of both SCNWC and SCLWC. This is because of pozzolanic and filler effect which is provided by the porous surface of bloated shale aggregate. This effect can be seen in the SEM images.
- Addition of Lightweight aggregate significantly improves the workability of SCLWC. This is due to the round shape of LWA. The slump flow of SCLWC is increased (1.39%) as compared with SCNWC while the flow time of SCLWC decreases (10%) as compared with SCNWC.
- Addition of LWA reduced the density of SCLWC up to 35%. This reduction in density can reduce the overall cost of the structure because of dead load reduction.

5.2 Concluding Remarks

A comprehensive and thorough study was carried out to examine the behavior of bloated shale lightweight aggregate on the performance of Self-consolidating concrete. From this study, it shows that the behavior of bloated shale in SCC has much improved as compared to SCNWC. From this study, it was concluded that bloated shale should be used in concrete to get cost-effective and high rise buildings with less self-weight of the structure.

References

1. Hwang, C.-L. and M.-F. Hung, *Durability design and performance of self-consolidating lightweight concrete.* Construction and Building Materials, 2005. **19**(8): p. 619-626.
2. Shafigh, P., et al., *A comparison study of the fresh and hardened properties of normal weight and lightweight aggregate concretes.* Journal of Building Engineering, 2018. **15**: p. 252-260.
3. Rizwan, S.A., *High-performance mortars and concrete using secondary raw materials.* 2006.
4. Okamura, H. and M. Ouchi, *Self-compacting concrete.* Journal of advanced concrete technology, 2003. **1**(1): p. 5-15.
5. Lo, T., et al., *Comparison of workability and mechanical properties of self-compacting lightweight concrete and normal self-compacting concrete.* Materials research innovations, 2007. **11**(1): p. 45-50.
6. Yoğurtcu, E., Ş. Yazıcı, and K. Ramyar, *Self-compacting lightweight aggregate concrete: design and experimental study.* Magazine of Concrete Research, 2009. **61**(7): p. 519-527.
7. Hanif, A., et al., *Effects of different lightweight functional fillers for use in cementitious composites.* International Journal of Concrete Structures and Materials, 2017. **11**(1): p. 99-113.
8. Hanif, A., et al., *Green lightweight cementitious composite incorporating aerogels and fly ash cenospheres–Mechanical and thermal insulating properties.* Construction and Building Materials, 2016. **116**: p. 422-430.
9. *Guide for Structural Lghtweight-Aggregate Concrete ACI213R-87 (Reapproved 1999)*. 1999.
10. Kramar, D. and V. Bindiganavile, *Impact response of lightweight mortars containing expanded perlite.* Cement and Concrete Composites, 2013. **37**: p. 205-214.
11. Sengul, O., et al., *Effect of expanded perlite on the mechanical properties and thermal conductivity of lightweight concrete.* Energy and Buildings, 2011. **43**(2-3): p. 671-676.
12. Kramar, D. and V. Bindiganavile, *Mechanical properties and size effects in lightweight mortars containing expanded perlite aggregate.* Materials and Structures, 2011. **44**(4): p. 735-748.
13. Topçu, İ.B. and B. Işıkdağ, *Effect of expanded perlite aggregate on the properties of lightweight concrete.* Journal of materials processing technology, 2008. **204**(1-3): p. 34-38.
14. Mladenovič, A., et al., *Alkali–silica reactivity of some frequently used lightweight aggregates.* Cement and Concrete Research, 2004. **34**(10): p. 1809-1816.
15. Lu, Z., et al., *Preparation and characterization of expanded perlite/paraffin composite as form-stable phase change material.* Solar Energy, 2014. **108**: p. 460-466.
16. Shi, C. and Y. Wu, *Mixture proportioning and properties of self-consolidating lightweight concrete containing glass powder.* Materials Journal, 2005. **102**(5): p. 355-363.
17. Nemes, R. and Z. Józsa, *Strength of lightweight glass aggregate concrete.* Journal of materials in civil engineering, 2006. **18**(5): p. 710-714.
18. Torres, M.L. and P. García-Ruiz, *Lightweight pozzolanic materials used in mortars: Evaluation of their influence on density, mechanical strength and water absorption.* Cement and Concrete Composites, 2009. **31**(2): p. 114-119.
19. Ghourchian, S., et al., *An investigation on the use of zeolite aggregates for internal curing of concrete.* Construction and Building Materials, 2013. **40**: p. 135-144.

20. Miled, K., K. Sab, and R. Le Roy, *Particle size effect on EPS lightweight concrete compressive strength: experimental investigation and modelling.* Mechanics of Materials, 2007. **39**(3): p. 222-240.
21. Bouvard, D., et al., *Characterization and simulation of microstructure and properties of EPS lightweight concrete.* Cement and Concrete Research, 2007. **37**(12): p. 1666-1673.
22. Le Roy, R., E. Parant, and C. Boulay, *Taking into account the inclusions' size in lightweight concrete compressive strength prediction.* Cement and concrete research, 2005. **35**(4): p. 770-775.
23. Baetens, R., et al., *Vacuum insulation panels for building applications: A review and beyond.* Energy and Buildings, 2010. **42**(2): p. 147-172.
24. Chen, B. and N. Liu, *A novel lightweight concrete-fabrication and its thermal and mechanical properties.* Construction and building materials, 2013. **44**: p. 691-698.
25. Koehler, E.P. and D.W. Fowler, *Inspection manual for self-consolidating concrete in precast members*. 2007, Center for Transportation Research, University of Texas at Austin.
26. Vakhshouri, B., *Compressive strength and mixture proportions of self-compacting light weight concrete.* 2017.
27. Tattersall, G.H., *Workability and quality control of concrete*. 2003: CRC Press.
28. Topçu, I.B. and T. Uygunoğlu, *Effect of aggregate type on properties of hardened self-consolidating lightweight concrete (SCLC).* Construction and Building Materials, 2010. **24**(7): p. 1286-1295.
29. Illidge, F.A.B., *Acoustic emission techniques and cyclic load testing for integrity evaluation of self-compacting normal and self-compacting lightweight prestressed concrete girders*. 2010, University of South Carolina.
30. Juradin, S., G. Baloević, and A. Harapin, *Experimental testing of the effects of fine particles on the properties of the self-compacting lightweight concrete.* Advances in Materials Science and Engineering, 2012. **2012**.
31. YAŞAR, E., C.D. ATIŞ, and A. Kiliç, *High strength lightweight concrete made with ternary mixtures of cement-fly ash-silica fume and scoria as aggregate.* Turkish Journal of Engineering and Environmental Sciences, 2004. **28**(2): p. 95-100.
32. Khayat, K.H., et al., *Use of Lightweight Sand for Internal Curing to Improve Performance of Concrete Infrastructure*. 2018.
33. Ali, M., et al., *Thermal-resistant lightweight concrete with polyethylene beads as coarse aggregates.* Construction and Building Materials, 2018. **164**: p. 739-749.
34. Lu, Z., et al., *A novel lightweight cementitious composite with enhanced thermal insulation and mechanical properties by extrusion technique.* Construction and Building Materials, 2018. **163**: p. 446-449.
35. Thomas, M.S. and M.M. Vadivel, *INNOVATIVE USE OF LIGHT WEIGHT FIBER REINFORCED CONCRETE AS 'CONCRETE CAR BUMPER'.* 2016.
36. Neville, A.M., *Properties of concrete*. Vol. 4. 1995: Longman London.
37. Tang, P. and H. Brouwers, *The durability and environmental properties of self-compacting concrete incorporating cold bonded lightweight aggregates produced from combined industrial solid wastes.* Construction and Building Materials, 2018. **167**: p. 271-285.

38. Andiç-Çakır, Ö., et al., *Self-compacting lightweight aggregate concrete: design and experimental study.* Magazine of Concrete Research, 2009. **61**(7): p. 519-527.
39. Kim, Y., et al., *Slag waste incorporation in high early strength concrete as cement replacement: Environmental impact and influence on hydration & durability attributes.* Journal of Cleaner Production, 2018. **172**: p. 3056-3065.
40. Ahmed, W., et al., *Effective use of sawdust for the production of eco-friendly and thermal-energy efficient normal weight and lightweight concretes with tailored fracture properties.* Journal of Cleaner Production, 2018. **184**: p. 1016-1027.
41. Wu, Z., et al., *An experimental study on the workability of self-compacting lightweight concrete.* Construction and Building Materials, 2009. **23**(5): p. 2087-2092.
42. Brouwers, H. and H. Radix, *Self-compacting concrete: theoretical and experimental study.* Cement and Concrete Research, 2005. **35**(11): p. 2116-2136.
43. Rizwan, S.A., T.A. Bier, and K. Dombrowski, *A Discussion on the Essential Issues for the Successful Production of Self-Compacting Concrete (SCC)*, in *Brittle Matrix Composites 8*. 2007, Elsevier. p. 149-159.
44. Mehta, P.K., *Advancements in concrete technology.* Concrete International, 1999. **21**(6): p. 69-76.
45. Rizwan, S.A. and T.A. Bier. *Early volume changes of high performance self-compacting cementitious systems containing pozzolanic powders*. in *International RILEM Conference on Volume Changes of Hardening Concrete: Testing and Mitigation*. 2006. RILEM Publications SARL.
46. Khayat, K., A. Ghezal, and M. Hadriche, *Utility of statistical models in proportioning self-consolidating concrete.* Materials and structures, 2000. **33**(5): p. 338-344.
47. Castro, J., et al., *Absorption and desorption properties of fine lightweight aggregate for application to internally cured concrete mixtures.* Cement and Concrete composites, 2011. **33**(10): p. 1001-1008.
48. Kim, Y.J., Y.W. Choi, and M. Lachemi, *Characteristics of self-consolidating concrete using two types of lightweight coarse aggregates.* Construction and Building Materials, 2010. **24**(1): p. 11-16.
49. Vakhshouri, B. and S. Nejadi, *Mix design of light-weight self-compacting concrete.* Case Studies in Construction Materials, 2016. **4**: p. 1-14.
50. Neville, A., *Properties of concrete (4th and final ed.) Pearson Education Limited.* Harlow, United Kingdom, 1997.
51. Schuitemaker, E., K. Van Breugel, and J. Den Uijl. *Design of self-compacting lightweight concrete with environment-friendly lightweight aggregate*. in *International RILEM Symposium on Self-Compacting Concrete*. 2003. RILEM Publications SARL.
52. Choi, Y.W., et al., *An experimental research on the fluidity and mechanical properties of high-strength lightweight self-compacting concrete.* Cement and Concrete Research, 2006. **36**(9): p. 1595-1602.
53. Rizwan, S.A. and T.A. Bier, *Blends of limestone powder and fly-ash enhance the response of self-compacting mortars.* Construction and building materials, 2012. **27**(1): p. 398-403.